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Modernizing the Mobility Air Force for Tomorrow's Air Traffic Management System

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Preface

Air Mobility Command (AMC) operates many of the largest aircraft in the U.S. Air Force and is the biggest fuel consumer in the U.S. Department of Defense. Without avionics modernization, the mobility air forces would lack some of the communication, navigation, and surveillance (CNS) capabilities required under forthcoming air traffic management (ATM) mandates. Noncompliant aircraft would be restricted to less efficient cruising altitudes and could face additional operating restrictions, leading to increased fuel usage and flying hours.

In 2009, RAND Project AIR FORCE published a study that examined the cost-effectiveness of modernizing the KC-10 aerial refueling tanker to comply with these mandates (Rosello et al., 2009). That work showed that modernization was robustly cost-effective across a wide range of assumptions. At the request of AMC, RAND conducted a similar analysis of ongoing modernization programs and additional upgrades for compliance with CNS/ATM mandates for the Air Force's C-5, C-17, KC-135, and C-130 fleets. This work estimates the cost avoidance associated with CNS/ATM compliance and the potential impacts of noncompliance on the wartime mission to determine whether the upgrades are cost-effective.

After this research was completed, the Air Force, in its fiscal year (FY) 2013 proposed budget, communicated its intent to make changes to the mobility fleets. The changes proposed by the Air Force included retiring the 65 oldest C-130s, reducing the scope of the C-130 avionics modernization program, retiring all C-5As, and retiring 20 KC-135s. As of this writing, Congress had not responded to the proposal; therefore, this monograph refers to the existing fleets and programs as presented in the FY 2012 President's Budget. If the changes are implemented, the total cost-avoidance values presented here would be reduced. However, the overall findings would remain the same qualitatively.

This research was sponsored by the Commander of AMC and the Deputy Assistant Secretary of the Air Force for Energy, Office of the Assistant Secretary of the Air Force for Installations, Environment, and Logistics. The study was conducted within the Resource Management Program of RAND Project AIR FORCE as part of the FY 2011 project "Increasing the Fuel Efficiency of Air Force Mobility Operations." This monograph should be of interest to members of the defense acquisition community who are involved with aircraft modernization, particularly how it relates to fuel efficiency and airspace access as ATM systems around the world are transformed.

RAND Project AIR FORCE

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Summary

As airspace systems around the world are transformed to accommodate growing air traffic demands, the U.S. Air Force must decide whether to modernize its fleets to comply with new equipage mandates. Without avionics modernization, the Mobility Air Force's C-5, C-17, KC-135, and C-130 fleets would lack some of the capabilities required to meet these forthcoming mandates. Modernization ensures continued access to fuel-efficient cruising altitudes and congested airspace, but these future benefits require an upfront investment in avionics upgrade programs.

The Air Force plans to operate legacy aircraft well into the future. As they age, these fleets will require modernization to maintain their capabilities. In a fiscally constrained environment, investment decisions must be made in a way that maximizes the benefit of each dollar spent. This analysis looks at a subset of these potential investments, assessing their cost-effectiveness based on quantifiable future costs that would be avoided by modernization. For some programs, there may be additional benefits beyond those resulting from communication, navigation, and surveillance/air traffic management (CNS/ATM) cost avoidance. In many cases, these outcomes reinforce the results presented here. In others, the broader potential benefits must be weighed carefully against program costs that are not fully offset by CNS/ATM cost avoidance.

Throughout this monograph, *cost avoidance* refers to the net present value of all operating and support costs that would be avoided over the remaining service life of an aircraft by modernizing to comply

with CNS/ATM mandates. In addition to these steady-state operating costs, we considered the impacts of noncompliance on the warfighting mission separately, based on the additional equivalent aircraft capacity required each year to maintain the same capability level as a fully compliant fleet.

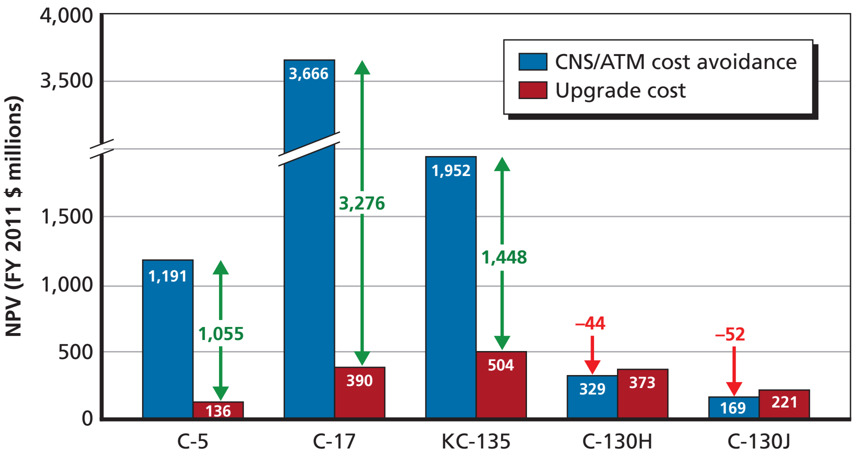
After this research was completed, the Air Force, in its FY 2013 proposed budget, communicated its intent to make changes to the mobility fleets. The changes proposed by the Air Force included retiring the 65 oldest C-130s, reducing the scope of the C-130 avionics modernization program (AMP), retiring all C-5As, and retiring 20 KC-135s. As of this writing, Congress had not responded to the proposal; therefore, this monograph refers to the existing fleets and programs as presented in the FY 2012 President's Budget. If the changes are implemented, the total cost-avoidance values presented here would be reduced. However, the overall findings would remain the same qualitatively.

Much of the cost avoidance is due to preventing the increased fuel usage that would result from mandates that restrict aircraft from cruising at the most fuel-efficient altitudes. The most severe flight-level restriction would result from noncompliance with the mandate for Automatic Dependent Surveillance–Broadcast Out (ADS-B Out), a surveillance capability that will be required in the United States starting in 2020 for aircraft to fly above 10,000 feet and access the nation's busiest airports.[1] None of the aircraft examined in this study are currently ADS-B Out–capable. Figure S.1 compares the upgrade cost for compliance and the resulting cost avoidance for each aircraft fleet. The cost avoidance exceeds the upgrade cost for the C-5, C-17, and KC-135; therefore, upgrade programs are cost-effective for these aircraft based on CNS/ATM cost avoidance alone, netting more than $5.7 billion over their remaining service lives.

In contrast, C-130 noncompliance would result in far lower operating cost penalties, since these fleets fly at lower altitudes and burn

[1] The ADS-B Out rulemaking allows noncompliant aircraft to climb above 10,000 feet if they would otherwise be within 2,500 feet above ground level. This would allow these aircraft to transit large mountain ranges.

Figure S.1
CNS/ATM Cost Avoidance Versus Upgrade Cost for ADS-B Out Modernization



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less fuel than the heavier aircraft. C-130 ADS-B Out modernization is cost-effective only if the upgrade can be accomplished for no more than $1.5 million per aircraft for the H model and $1.3 million per aircraft for the J model—less than the conservative estimates used in this study—or fuel prices increase to $3.50 per gallon for the H model and $4.00 per gallon for the J model. However, failure to modernize would restrict access to Class B and C airspace, which surrounds many of the busiest airports in the United States. This includes several joint civil-military bases where C-130s are currently stationed. If these aircraft must be rebased due to ADS-B Out noncompliance, the case for modernization would be strengthened, since the upgrade would result in additional cost avoidance.

There are ongoing modernization programs in place to address the other CNS/ATM capability shortfalls for the C-5, C-17, and C-130. This study found that the C-5 AMP and the C-17 Global Air Traffic Management/Required Navigation Performance–1 (GATM/RNP-1) programs are cost-effective, netting $10 million and $219 million, respectively. The C-130H AMP costs are estimated to exceed the CNS/ATM cost avoidance by more than $3.2 billion. The cost-effectiveness of this program may be justified by other benefits, including reduced manpower costs, increased reliability and maintainability, and fleet commonality, but their examination was beyond the scope of this study. Similarly, the C-130J Block 7 upgrade program cost was found to exceed the CNS/ATM cost avoidance by $80 million under the baseline fuel price assumptions.

In addition to steady-state operating cost avoidance that exceeds the upgrade costs, the ADS-B Out and ongoing modernization programs for the C-5 and C-17 are required to maintain the wartime capability of the strategic airlift fleet, which would otherwise be degraded by flight restrictions resulting from noncompliance. The C-130 intratheater airlift mission would not be affected by noncompliance with CNS/ATM mandates because the military would control the airspace in which C-130 combat operations would take place. While some tanker missions would be affected, the KC-135 will retain full wartime capability based on planned compliance with all mandates by their implementation dates.

Acknowledgments

We are grateful for the support of our project sponsors, Gen Raymond Johns, Commander, Air Mobility Command, and Kevin Geiss, Deputy Assistant Secretary of the Air Force for Energy, Office of the Assistant Secretary of the Air Force for Installations, Environment, and Logistics. We also thank our action officers in the Air Mobility Command Air, Space, and Mobility Operations Directorate (AMC/A3) Fuel Efficiency Office, Col Bobby Fowler, Col Kevin Trayer, and Maj Darren Loftin. Their guidance and assistance throughout this study was invaluable.

We relied on the expertise and input of numerous staff in offices throughout the Air Force, including the system program offices for the C-5, C-17, KC-135, C-130 AMP, and C-130J; ESC/HBAI; the Air Force Flight Standards Agency; the Office of the Assistant Secretary of the Air Force for Acquisition, Global Reach Programs (SAF/AQQ); the Energy Aviation Operations Working Group in the Office of the Deputy Chief of Staff for Operations, Plans and Requirements (AF/A3/5); the Office of Bases, Ranges, and Airspace (AF/A3O-B); AMC's Analysis, Assessments, and Lessons Learned Directorate (AMC/A9); and AMC's Strategic Plans, Requirements, and Programs Directorate (AMC/A5/8).

We also thank our RAND colleagues who contributed to this work. The leadership of Laura Baldwin, our program director, was key to producing a thorough analysis in the abbreviated time frame requested by our sponsor. Ronald McGarvey, David Orletsky, and Christopher Mouton shared relevant data from their ongoing studies and provided numerous critiques that strengthened our analysis. The suggestions provided by our technical reviewers, Jim Powers, James Dryden, and John Gibson, made for a greatly improved final document. Finally, we thank Jane Siegel for carefully preparing and formatting multiple iterations of this document under tight deadlines; Lauren Skrabala for greatly enhancing the readability of our document through meticulous final editing of the text and figures; and Kimbria McCarty for patiently managing the production process.

Abbreviations

ADS-B	Automatic Dependent Surveillance–Broadcast
ADS-C	Automatic Dependent Surveillance–Contract
AMC	Air Mobility Command
AMP	avionics modernization program
AoA	analysis of alternatives
ATC	air traffic control
ATM	air traffic management
ATN	Aeronautical Telecommunications Network
CNS	communication, navigation, and surveillance
COCOM	combatant command
CPDLC	controller-pilot data-link communication
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FL	flight level
FM	frequency modulation
FY	fiscal year
GATM	Global Air Traffic Management

GDSS	Global Decision Support System
GLONASS	Global'naya Navigatsionnaya Sputnikovaya Sistema [Global Navigation Satellite System]
GPS	Global Positioning System
HF	high frequency
ICAO	International Civil Aviation Organization
MAF	mobility air forces
Mode S	Mode-Select
NPV	net present value
OEP	Operational Evolution Partnership
Pacer CRAG	Pacer Compass Radar and Global Positioning System
PAF	RAND Project AIR FORCE
PRNAV	Precision Area Navigation
RNAV	Area Navigation
RNP	Required Navigation Performance
RVSM	reduced vertical separation minimum
SAASM	Selective Availability/Anti-Spoofing Module
SATCOM	satellite communication
SPARC	Strategic Projection of Airspace Requirements and Certifications
USAFRICOM	U.S. Africa Command
USCENTCOM	U.S. Central Command
USEUCOM	U.S. European Command
USPACOM	U.S. Pacific Command

USSOUTHCOM	U.S. Southern Command
VDL	very-high-frequency data link
VHF	very high frequency

CHAPTER ONE

Introduction

As airspace systems around the world are transformed to accommodate growing air traffic demands, the U.S. Air Force must decide whether to modernize its fleets to comply with new equipage mandates. Modernization ensures continued access to fuel-efficient cruising altitudes and congested airspace, but these future benefits require an upfront investment in avionics upgrade programs. In a fiscally constrained environment, such investment decisions must be made in a way that maximizes the benefit of each dollar spent based on quantifiable future costs that would be avoided by modernization.

In 2009, RAND Project AIR FORCE (PAF) published a study that examined the cost-effectiveness of modernizing the KC-10 aerial refueling tanker to comply with forthcoming communication, navigation, and surveillance/air traffic management (CNS/ATM) mandates. That work showed that modernization was robustly cost-effective across a wide range of assumptions (Rosello et al., 2009). As requested by Air Mobility Command (AMC), this study extends that analysis to the C-5, C-17, C-130, and KC-135 fleets.

The Air Force operates a fleet of mobility aircraft spanning a broad spectrum of age—from the KC-135, which has been in service for more than 50 years, to the C-17 and C-130J, which are currently in production. While the level of modernization and CNS/ATM capability varies among the aircraft examined here, most have considerable service life remaining before their retirement and need to be capable of operating with future airspace systems. Those that do not comply with equipage mandates risk additional operating costs and reduced wartime effectiveness resulting from flight-level restrictions, delays, and other consequences of noncompliance.

If aircraft were modernized to meet the mandates, they would likely maintain a similar flying-hour program and level of fuel use in future years. If they do not comply, the flying hours required to accomplish the same set of missions would increase along with fuel use per flying hour, thereby increasing the cost of steady-state operations. In some cases, modernization would also be necessary to *maintain* the current level of operational effectiveness in wartime missions, because noncompliant aircraft may be *less capable* of carrying out the same missions.

This monograph examines a variety of modernization paths for the Air Force's C-5, C-17, C-130, and KC-135 fleets, including ongoing upgrade programs and other changes that are required to close future capability gaps. For each aircraft, we estimated the net present value (NPV) of changes in steady-state operating costs that would result from noncompliance. We then compared these values to the acquisition costs required to avoid them. For some programs, there may be additional benefits beyond those resulting from CNS/ATM cost avoidance. In many cases, these outcomes reinforce the results presented here. In others, the broader potential benefits must be weighed carefully against program costs that are not fully offset by CNS/ATM cost avoidance.

The next chapter introduces the relevant CNS/ATM capabilities, the associated mandates, and the potential effects on aircraft that do not comply. Chapter Three details the methodology used to determine the cost-effectiveness of the various modernization paths considered for each aircraft. Chapters Four through Eight present the results for the C-5, C-17, KC-135, and C-130, respectively. Finally, Chapter Nine summarizes the important conclusions from the analysis. Two appendixes provide a detailed description of the CNS/ATM capabilities described in Chapter Two and show the steady-state operations profile for each aircraft, respectively.

CHAPTER TWO

CNS/ATM Capabilities and Mandates

Equipage Mandates

Airspace modernization decisions affect a wide range of parties, including private pilots, commercial airlines, military aviation users, and air traffic service providers. These groups benefit from improved operational efficiency, increased safety levels, and lower operating costs. As a result, they help drive changes in technical and operational standards by identifying needs and participating in working groups and committees. The result of this consensus-based process is a set of standards, such as minimum operational performance standards and the International Civil Aviation Organization's (ICAO's) Standards and Recommended Practices. Other standardization organizations that are responsible for producing recommendations include the European Organisation for Civil Aviation Equipment, European Aviation Safety Agency/Joint Aviation Authorities, Radio Technical Commission for Aeronautics, and the Federal Aviation Administration (FAA).[1]

In addition, governmental agencies, such as the FAA, develop legal mandates and certification requirements to regulate the implementation of new CNS/ATM capabilities, often basing their mandates on the consensus-developed standards. National mandates and standards are usually disseminated through Aeronautical Information Publications, Federal Aviation Regulations, type certificates, and other sources. While each individual country is responsible for laws govern-

[1] This chapter draws heavily from an earlier RAND study (Rosello et al., 2009), with updates to reflect recent changes to CNS/ATM mandates.

ing its airspace, regional organizations (such as ICAO and Eurocontrol, Europe's air safety organization) often guide policy by issuing "specimen" aeronautical information publications. This process allows continuity and reduces the burden on users to meet numerous disparate requirements as they transit from the airspace of one country to another (Hershey, 2008).

For this study, the global airspace requirements were broken down broadly by ICAO region definitions. We assumed that users not properly equipped to meet the mandates proposed for a given ICAO region would face some penalty or be denied some benefit of compliance; this could include denial from premium altitudes, increased delays resulting from suboptimal routing or spacing, and airspace exclusion. While military aircraft are sometimes granted waivers, we assume here that they will face the same penalties for noncompliance as civil aircraft. Some exemptions may still be granted in the future, but the expected growth in air traffic may limit the ability of noncompliant aircraft to operate in certain regions without causing significant disruption. Additionally, the worldwide volume of civil traffic compared to U.S. military traffic places the U.S. military in a clear minority.

CNS/ATM Overview

Implementation of global CNS/ATM mandates is expected over the next two decades. We categorized the mandates and standards into four major classes: communication, navigation, surveillance, and other.

Communication

Communication systems allow aircraft to communicate with ground-based air traffic controllers. Traditionally, this has been accomplished through line-of-sight very-high-frequency (VHF) radios and voice communication capabilities. Increasingly, air traffic control (ATC) communications rely on data links and beyond-line-of-sight radios (for example, those using satellite communication, or SATCOM, capabilities) instead of voice messages over VHF radios. In busy airspace, communication throughput limitations have restricted the number of aircraft that can access the airspace and increased the amount of time it takes to send and receive air traffic clearances. As a result, new communication capabilities have been mandated to increase communication capacity.

Navigation

Navigation systems allow aircraft to adequately maintain a specified route of flight to a given destination. Historically, navigation in aviation beyond pilotage (using ground references) has been accomplished through a variety of ground-based radio beacons. These systems provide some combination of bearing and distance information from which an aircraft can establish its position. Later advances in avionics allowed the aircraft to electronically query all ground-based navigation aids within range and automatically determine its position (as opposed to manually tuning in individual navigation aids to get bearing and distance information, or using information from multiple navigation aids to triangulate position). With the advent of global navigation satellite systems (e.g., the U.S. Global Positioning System, or GPS, and the Russian global navigation satellite system known as GLONASS), an additional source of position information was added, allowing the aircraft to globally determine its position with unparalleled accuracy independent of a ground-based network.

Recent and forthcoming navigation mandates require aircraft to determine their position independent of ground-based navigation aids, with varying degrees of accuracy, integrity, and availability. These mandates typically fall into one of two categories: Area Navigation (RNAV) or Required Navigation Performance (RNP).

RNAV is a method of aircraft navigation along any desired flight path. The specification implies an accuracy requirement that the lateral navigation error remain less than *x* nautical miles at least 95 percent of the flight time by the population of aircraft operating in the airspace, on the route, or in accordance with a given procedure (Meyer and Bradley, 2001). RNAV-1 has been required for certain terminal-area procedures in Europe since 2005, and the United States plans to require RNAV-2 for aircraft flying above 18,000 feet and RNAV-1 for arrivals and departures at the nation's busiest airports starting in 2015.

RNP prescribes the system performance necessary for operation in a specified airspace based on a given required accuracy (RNP value). The basic accuracy requirement for RNP-X airspace is for the aircraft to remain within *x* nautical miles of the cleared position for 95 percent of the time it is in RNP airspace. There is an additional containment requirement for RNP operations. According to ICAO, any potential deviation greater than twice the RNP value must be annunciated, with a probability of missed detection less than 10^{-5} (Meyer and Bradley, 2001). RNP-2 will be required for aircraft flying above 29,000 feet in the United States starting in 2015.

Surveillance

Surveillance systems allow air traffic controllers to independently track the location of individual aircraft. Historically, this was accomplished through ground-based radar. Next, aircraft were equipped with radar transponders that replied to radar interrogation with a unique identifying code and altitude. Recently, systems such as Automatic Dependent Surveillance–Broadcast Out (ADS-B Out) and Mode-Select (Mode S) have enabled aircraft to self-report surveillance information to ground-based ATC systems and to other aircraft for collision avoidance. ADS-B Out is an integral part of the FAA's airspace modernization efforts, with a final rule published in 2010 that mandates equipage starting in 2020 to fly above 10,000 feet and to access the nation's busiest airports.

Increasingly accurate surveillance and navigation systems allow aircraft to fly closer together without reducing the margin of safety. This closer spacing allows for a greater throughput capacity, thus reducing congestion and delays.

Some benefits of airspace modernization can be attained only through combinations of CNS systems. For example, access to Future Air Navigation System (FANS) airspace requires ADS-Contract (ADS-C), controller-pilot data-link communication (CPDLC), and the ability to automatically log in to each controlling agency as the aircraft enters its airspace (facilities notification).[2] Currently, FANS-1/A capability is required for 30/30 separation in some oceanic regions, and

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[2] In this monograph, we refer to the current system standard, FANS-1/A.

equipped aircraft in operation today will also be exempt from the European mandate for the Aeronautical Telecommunications Network/CPDLC.[3,4]

Other

Other mandates levied for military necessity or safety reasons span the navigation safety, instrument approach, and military navigation and surveillance categories.

Navigation safety mandates may include terrain avoidance systems or aircraft collision avoidance systems. While these systems are important and improve safety, they do not generally increase access to airspace.

Instrument approach capabilities allow pilots to fly without visual reference to the ground down to various altitudes while landing. They thus allow pilots to operate aircraft at lower altitudes during approaches before making the decision to continue for landing or to "go around." These systems may allow landing in low-visibility conditions at airports that do not have other ground-based landing systems. However, instrument approach systems are not required for airspace access and generally allow increased airport access only in areas where there is poor aviation infrastructure. Large transport-category aircraft, like many of those examined in this study, often operate from larger airports that already have the ground-based navigation aids for landing in low-visibility conditions.

Military navigation and surveillance mandates may include specific systems that counter enemy jamming or eavesdropping efforts. Examples of these types of systems are Mode 5 and the Selective Availability/Anti-Spoofing Module (SAASM). Like the other capabilities in this class, they generally do not increase access to civil airspace. However, they do add military value and may be satisfied in conjunction

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[3] The term *30/30 separation* refers to a "30 nm lateral/30 nm longitudinal separation standard [that] permits suitably equipped aircraft to operate in closer proximity to each other to effectively utilize the airspace in a more efficient manner" (ISPACG, 2006).

[4] Specifically, "FANS aircraft with an initial individual airworthiness certificate issued before 1 January 2014 are exempted from the provisions of the [data-link services implementation rule] for their whole lifetime" (Eurocontrol, undated[a]).

with other mandates. For example, if a particular embedded GPS or inertial navigation system is placed in an aircraft to satisfy a given navigation requirement, a GPS receiver that has SAASM capability could also satisfy the SAASM military-mandated requirement.

These safety and military mandates do not affect access to civil airspace or the cost-effectiveness analysis presented here.

Descriptions of specific CNS/ATM capabilities can be found in Appendix A.

Current and Future CNS/ATM Mandates

Chapters Four through Eight discuss the current capabilities of each aircraft examined in our study, along with any ongoing or planned modernization programs. We use a matrix to show compliance status with respect to existing and projected CNS/ATM capabilities and standards. As an example, Table 2.1 summarizes the current C-5 capabilities and modernization programs that are discussed in Chapter Four. For each capability in the table, a check mark indicates compliance upon completion of the corresponding modernization program and an "X" identifies capabilities that will not be addressed by any planned programs.

Aircraft that are not compliant with the mandates are subject to the restrictions or penalties established by individual national ATC authorities. Each country may establish unique equipage and certification requirements for airspace access, as well as penalties for noncompliance with its mandates. Even though each country can regulate and enforce its own airspace access, countries typically coordinate regionally to facilitate air traffic operations. Figure 2.1 shows the current and projected CNS/ATM mandates that could affect the aircraft included in our study, grouped by ICAO region definition.

An aircraft that is not compliant with a given CNS/ATM mandate is restricted from the most congested altitudes (which are the most fuel-efficient) and may be subject to airborne delays. The practical effect of altitude restrictions is to limit the maximum altitude of a noncompliant aircraft. In Figure 2.1, these maximum altitudes

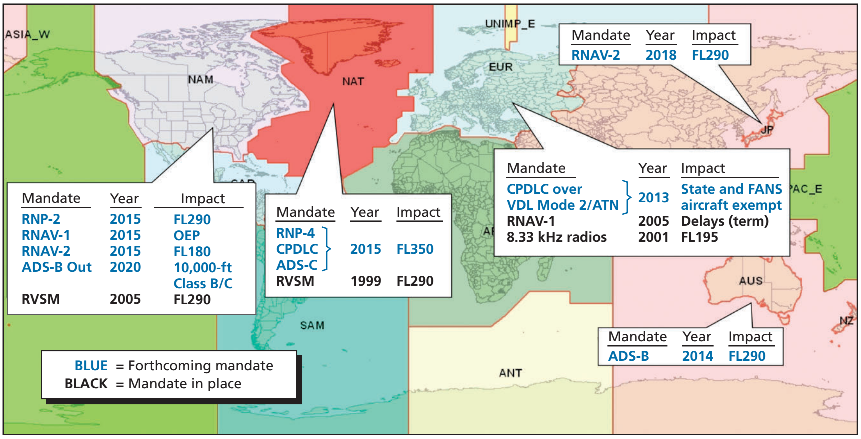
Table 2.1
Current C-5 Capabilities and Avionics Upgrade Programs

		Avionics Upgrade Programs	
Category	**Capability**	**AMP**	**ADS-B Out**
Communication	8.33-kHz VHF	Existing capability	
	CPDLC/FANS	√	
	SATCOM data link	√	
	SATCOM voice	√	
	VHF data link (VDL Mode 2)	X	X
Navigation	RNAV-1 (precision RNAV, or PRNAV)	√	
	RNAV-2 (U.S. RNAV)	√	
	RNP-4 (oceanic/remote)	√	
	RNP-0.3/1/2	√	
	Reduced vertical separation minimum (RVSM)	Existing capability	
Surveillance	ADS-B Out		√
	Mode S enhanced surveillance	√	

are expressed in terms of flight levels (FLs), which equate to hundreds of feet above mean sea level. Thus, FL180 corresponds to 18,000 feet above mean sea level.

If the impact of noncompliance is delays, then "delays" is shown in the "impact" column for each ICAO region in Figure 2.1. Sometimes, the impact involves access to and delays at busy U.S. airports (specifically, those included in the FAA's Operational Evolution Partnership program, which are designated "OEP" airports) or to airport terminal areas. We used numerous sources of information to determine mandate dates and noncompliance effects, including the Strategic Projection of Airspace Requirements and Certifications (SPARC) database maintained by CNS/ATM experts from the 853rd Electronic Systems

Figure 2.1
Current and Projected Worldwide CNS/ATM Mandates with Potential Implications for the Aircraft in This Study



NOTE: ATN = Aeronautical Telecommunications Network.
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Group at Hanscom Air Force Base, Massachusetts;[5] implementing rules and other documents from the FAA, Eurocontrol, North Atlantic Systems Planning Group, and other relevant civil aviation authorities; and input from experts in the Air Force and civilian aviation communities.

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5 SPARC is a software application prepared by the Air Force Electronic Systems Center's Global Air Traffic Management Office. It displays global and regional maps based on CNS/ATM implementation schedules, displays Air Force platform CNS/ATM schedules, analyzes global civilian flight routes, and examines noncompliance impacts resulting from CNS/ATM implementation.

CHAPTER THREE

Methodology for Cost-Effectiveness Analysis

Operating Cost Avoidance from CNS/ATM Modernization

In this study, we evaluated the cost-effectiveness of CNS/ATM modernization programs by comparing the upgrade cost to the operating cost avoidance that would result from the increased capability. Figure 3.1 illustrates the analytical approach. For each year through 2040, we projected the compliance status of each aircraft in the mobility air forces (MAF) fleet based on expected CNS/ATM mandates and current modernization plans. Using a steady-state operations pattern derived from historical data for each aircraft type, we were able to apply the impacts of noncompliance where appropriate to estimate the resulting change in steady-state operating costs. We then compared these operating cost increases, which would be *avoided* by modernization, to the upgrade costs to determine which programs are cost-effective.

For aircraft whose wartime missions are affected by noncompliance with CNS/ATM mandates, we also determined the shortfall in wartime capability given the effectiveness degradation that would result. Avoiding any wartime capability shortfalls strengthens the case for modernization. The methodology for modeling the wartime missions is discussed later in this chapter.

Steady-State Operations Pattern

AMC plans and tracks MAF operations using the Global Decision Support System (GDSS), which contains information about each sortie flown, including the origin and destination bases, mission type, payload weight, and number of passengers. Figure 3.2 shows great circle

Figure 3.1
Analytical Approach

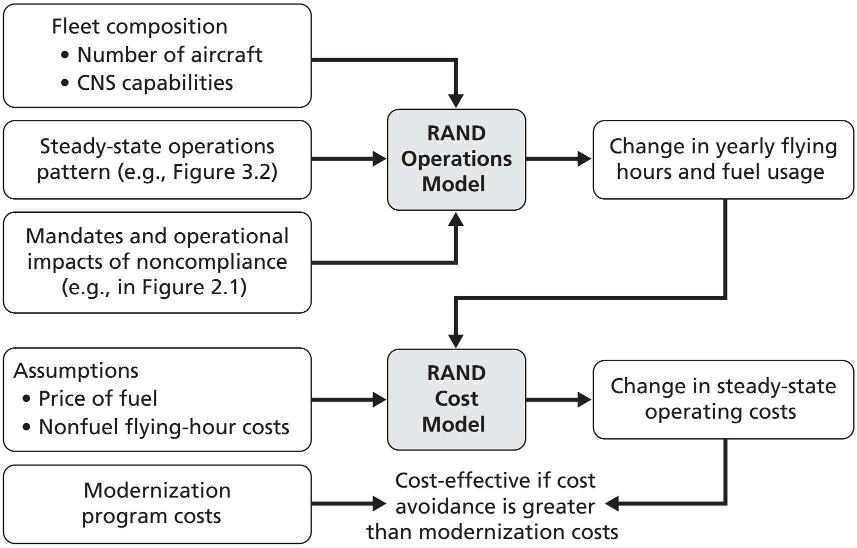

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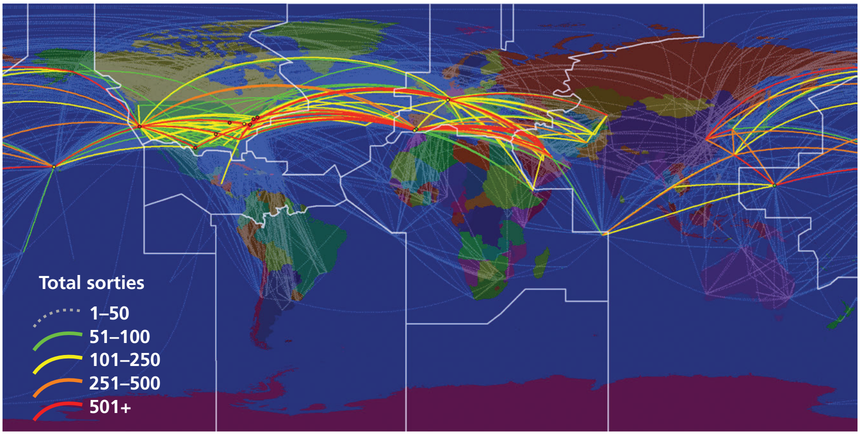
Figure 3.2
C-5 Steady-State Operations Pattern, 2000–2010



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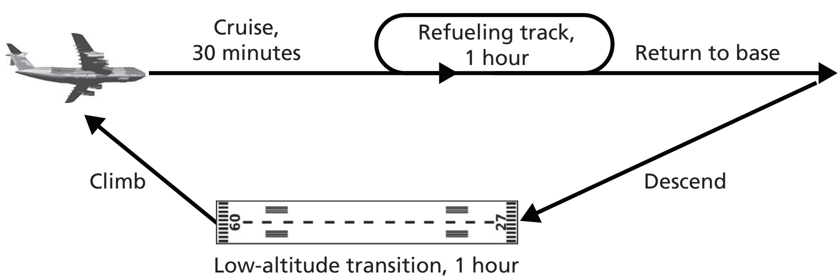
routes connecting the base pairs listed in GDSS for the C-5 during the period from 2000 to 2010. As indicated by the legend, the orange and red lines represent the most commonly flown routes. As expected, a large amount of flying takes place in North America and between North America, Europe, and current areas of operation in Central Asia.

We reproduced each sortie in the data set in our analytical model to create a baseline flying pattern for this analysis. Some sorties depart and arrive at the same base. These are often training missions, and GDSS does not include sufficient detail to reconstruct them without additional data. Therefore, we consulted with operational units to create representative flight profiles for this subset of missions. A portion of these missions is flown at low altitude "around the flagpole" and would not be affected by CNS/ATM mandates. The remaining missions typically include high-altitude segments that would be affected by the mandates. Figure 3.3 shows the flight profile used to represent this subset of missions for the C-5.

We used the flying pattern in the GDSS data set supplemented by the representative training flight profile as the baseline for C-5 steady-state operations through 2040. This pattern served as a basis for translating the regional impacts of noncompliance depicted in Figure 2.1 into fleet-wide fuel and flying-hour penalties.

Figure 3.3
Representative Flight Profile for C-5 High-Altitude Training Missions That Would Be Affected by CNS/ATM Mandates



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While the C-5 flying pattern is shown here as an example, we used the same approach for the C-17, KC-135, and C-130. For each aircraft type, we also varied the payload weight per sortie to parametrically capture the effect of variability in future mobility delivery requirements. The light-payload case corresponds to an empty payload bay for all missions, which bounds any potential variability on the light side. The heavy case selected for this analysis corresponds to half of the pallet positions being occupied, on average. This would occur if each mission were flown at maximum pallet capacity on the outbound leg and empty on the return leg, representing a substantial increase in the average steady-state payload for each aircraft type. The range of cost-effectiveness estimates corresponding to each payload case is presented in Chapters Four through Eight.

Impact of CNS/ATM Noncompliance on Fuel Use and Flying Hours

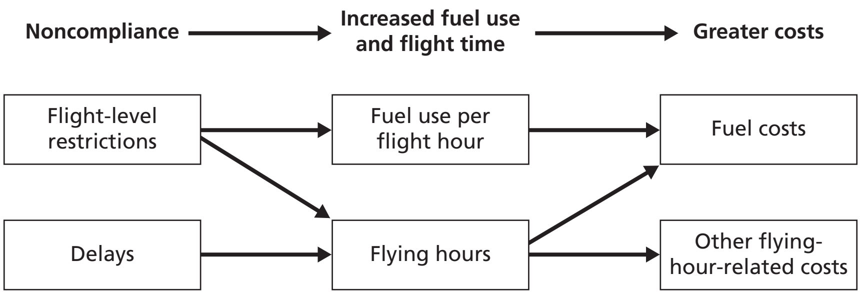
We grouped the impacts of noncompliance with CNS/ATM mandates into two categories: flight-level restrictions and delays. Flight-level restrictions lead to suboptimal cruise altitudes, which increase the fuel use per flight hour. In many cases, aircraft also cruise at slower speeds at these altitudes, leading to an increase in the number of flying hours required to fly the same sortie. Flight delays also lead to an increase in required flying hours. These increases in fuel use per flight hour and total flying hours translate into greater operating costs, as shown in Figure 3.4, through increases in total fuel costs and other nonfuel flying-hour-related costs.

Penalty factors, determined based on the steady-state flying pattern, were applied to the nominal fuel usage and yearly flying hours from the Air Force Total Ownership Cost database (AFTOC) and Logistics Installations and Mission Support–Enterprise View (LIMS-EV) database; we then determined the NPV of these changes through 2040 under a variety of assumptions.

Cost Avoidance from CNS/ATM Modernization

Modernizing to comply with CNS/ATM mandates prevents an increase in operating costs resulting from noncompliance. We measured this cost avoidance against the cost of the associated avionics

Figure 3.4
Operating Cost Implications of CNS/ATM Noncompliance



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upgrade programs. A modernization program is cost-effective when the cost avoidance exceeds the upgrade cost. Some programs provide additional benefits beyond CNS/ATM compliance, too. In these cases, the CNS/ATM cost avoidance for steady-state operations may provide only a partial justification for the investment decision.

Operational Benefits from CNS/ATM Modernization

Aircraft that modernize to meet CNS/ATM mandates will avoid the associated airspace restrictions and delays, maintaining the capability to execute future warfighting missions as planned. Those that face consequences from noncompliance may be less effective in the future as a result. Assuming that the fleet is sized appropriately in any given year to meet peak wartime mobility requirements without excess capacity, additional aircraft would be needed to maintain the required level of wartime capability, given the effectiveness degradation from CNS/ATM noncompliance. For this study, we examined the wartime missions for mobility aircraft to determine which missions would be affected by CNS/ATM mandates, estimated the decrease in effectiveness due to noncompliance, and determined the shortfall in wartime capability in terms of the number of additional aircraft that would be needed to accomplish the wartime mission. Definition and representation of these missions are based on air mobility operations doctrine found in Joint Publication 3-17 (U.S. Joint Chiefs of Staff, 2009), as well as the RAND KC-X analysis of alternatives (AoA) (Stillion, Orletsky, and Fitzmartin, 2005) and KC-10 modernization study (Rosello et al., 2009).[1]

Warfighting Missions

The MAF fleet performs a variety of missions during wartime. Whether or not each mission is affected by CNS/ATM mandates depends on the nature and location of the mission, as well as the compliance status of the aircraft that carries it out.

The primary wartime mission of the C-130 is to provide intratheater airlift, moving personnel and cargo within a theater of operations. There are several reasons to believe that the CNS/ATM mandates would not affect this mission. There is little or no civil air traffic in theater during major combat operations. The military would control the airspace before employing intratheater airlifters, which would not be subject to civil air traffic control. Rather, an air operations center would be established for airspace control. It is very unlikely in this scenario that the military would restrict the ability of its own aircraft to carry out the wartime mission. While there might be impacts during self-deployment to the area of responsibility, such scenarios represent a negligible portion of the overall flying that would occur over the course of the conflict.

The KC-135 provides aerial refueling in a variety of wartime missions, including homeland defense, Operations Plan 8010 (Strategic Deterrence and Global Strike), deployment, employment, global strike, air bridge, and national reserve.[2] While some of these missions may be affected by noncompliance with CNS/ATM mandates, we did not examine them in light of the KC-135's anticipated full compliance with all existing and future mandates.

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1 By "KC-X AoA," here and throughout this monograph, we are referring specifically to the "Analysis of Alternatives (AoA) for KC-135 Recapitalization" study conducted by RAND in 2005. The analysis presented here relied specifically on Appendix B in that series (Stillion, Orletsky, and Fitzmartin, 2005).

2 Descriptions of these missions can be found in Rosello et al. (2009), which examines the impact of CNS/ATM noncompliance on KC-10 steady-state and wartime operations.

Strategic airlifters deploy personnel, supplies, and equipment from an aerial port of embarkation within the United States to an aerial port of debarkation within the theater of operations. Since these aircraft transit great distances outside of theater and must consequently integrate with civil air traffic, the C-5 and C-17 deployment missions would be affected by noncompliance with CNS/ATM mandates.

Effects of Noncompliance on Wartime Effectiveness

The deployment movement requirements for a wartime scenario are outlined in a joint planning document, which specifies the time-phased lift requirements for the deployment in the form of time-phased force and deployment data (TPFDD). The measure of effectiveness for comparing strategic airlifter alternatives—in this case, a modernized airlifter versus an unmodernized one—is the relative number of aircraft required to "close" the TPFDD.[3] In other words, what fleet size is necessary to deliver the entire payload in the specified amount of time if specific aircraft are not fully modernized to comply with CNS/ATM mandates and if the fleet faces the consequences of noncompliance as a result?

Since the payload-carrying capability of the aircraft would not be diminished by CNS/ATM noncompliance, the effectiveness of an unmodernized aircraft would be degraded from that of a fully modernized one only in terms of the increased cycle time that results from certain flight-level restrictions and other flight delays.[4] The relative effectiveness of an unmodernized aircraft is thus defined as follows:

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[3] In transportation, the process of a unit arriving at a specified location. It begins when the first element arrives at a designated location (e.g., port of entry/port of departure, intermediate stops, or final destination) and ends when the last element does likewise. For the purposes of studies and command post exercises, a unit is considered essentially closed after 95 percent of its movement requirements for personnel and equipment are completed (Air Force Pamphlet 10-1403, 2011).

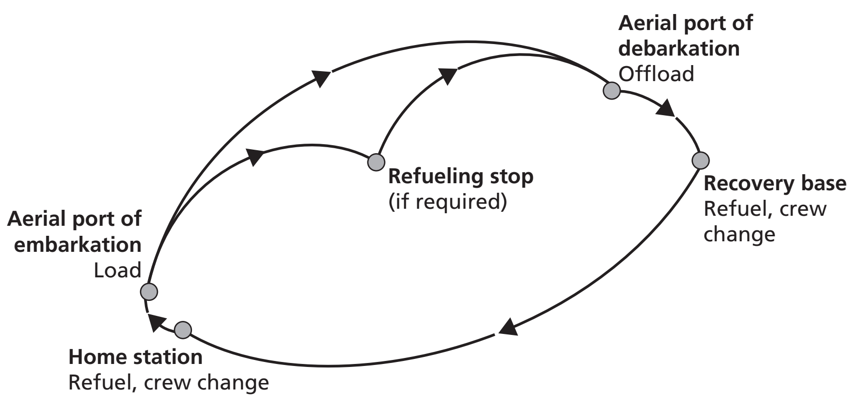
[4] The C-5 and C-17 typically "cube-out" before they "weight-out"; that is, the payload bay will usually reach its volume capacity before it reaches its maximum payload weight. The average payloads used in this study are derived from previous RAND analysis, as well as from the Joint Flow and Analysis System for Transportation, a transportation analysis model used by the U.S. Transportation Command. The average payloads for the C-17 are 61,500 lb (over and outsize) and 72,000 lb (bulk). For the C-5, they are 123,000 lb (over and outsize) and

$$\text{Effectiveness} = \frac{\text{Cycle time for modernized aircraft}}{\text{Cycle time for unmodernized aircraft}}.$$

Figure 3.5 depicts one deployment mission cycle, as modeled in this study, that includes positioning legs at each end of the cycle for refueling and crew changes, as well as refueling stops en route as needed for longer-distance missions. This construct, the time allocated to loading, unloading, and refueling, is consistent with Air Force planning (Air Force Pamphlet [AFPAM] 10-1403, 2011) and ongoing RAND research on intertheater airlift acquisition (Mouton et al., 2012).

The level of effectiveness degradation depends on the severity of the flight-time penalties, which vary by region according to the mandates and attendant impacts discussed in Chapter Two and presented in Figure 2.1. We examined a broad set of deployment missions by parametrically varying the deployment distance for each of the five combatant commands (COCOMs), as shown in Figure 3.6. The purpose was to capture regional differences in the penalties for noncompliance associated with deployments to various parts of the world.

Figure 3.5
One Deployment Mission Cycle



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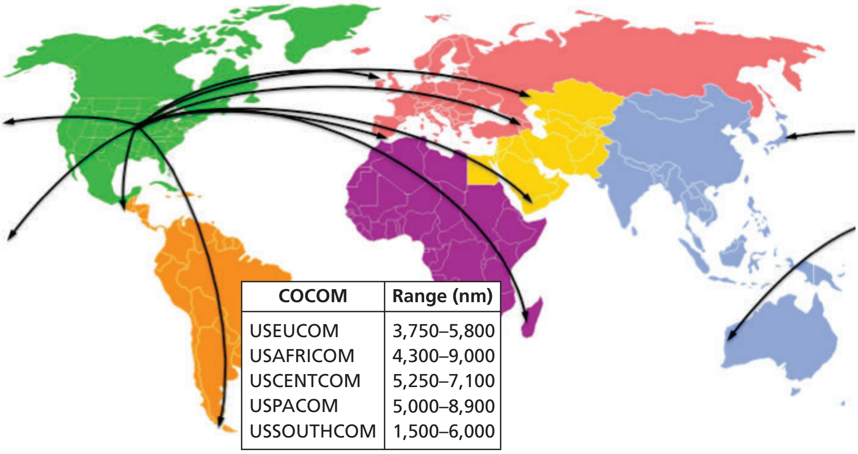
144,000 lb (bulk). Cycle time is the sum of round-trip flying time and round-trip ground time for a mission.

Figure 3.6
Short and Long Deployment Missions in Each COCOM



COCOM	Range (nm)
USEUCOM	3,750–5,800
USAFRICOM	4,300–9,000
USCENTCOM	5,250–7,100
USPACOM	5,000–8,900
USSOUTHCOM	1,500–6,000

NOTE: USEUCOM = U.S. European Command. USAFRICOM = U.S. Africa Command. USCENTCOM = U.S. Central Command. USPACOM = U.S. Pacific Command. USSOUTHCOM = U.S. Southern Command.

RAND *MG1194-3.6*

For each of the C-5 and C-17 modernization paths examined, we calculated the average effectiveness per COCOM. These effectiveness values varied according to the timing of the conflict, since there is temporal variation in the implementation of each mandate and the compliance status of each aircraft in the fleet. We then translated the degraded effectiveness of unmodernized aircraft into the number of those aircraft required to retain the same level of capability as a modernized, fully compliant fleet according to the following relationship:

$$\text{Number of unmodernized aircraft} = \frac{\text{Number of modernized aircraft}}{\text{Effectiveness}}.$$

Equipage Costs

To determine the cost-effectiveness of each avionics modernization program (AMP), we compared the upgrade cost to the associated cost avoidance from CNS/ATM compliance. We used several sources to estimate the cost of avionics modernization. For ongoing programs, we derived average unit procurement costs from Selected Acquisition Reports (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2010a, 2010b) and President's Budgets (Executive Office of the President, 2008, 2011). We used these sources for the C-5 AMP, C-17 Global Air Traffic Management/RNP-1 (GATM/RNP-1), C-130 AMP, and C-130J block upgrades; the results are presented in Chapters Four through Eight.

There are no ongoing ADS-B Out modernization programs in the MAF, and cost estimates for this capability vary widely. As a result, we used several sources to inform a conservative estimate that we could use across the board for each aircraft in the study. In its regulatory evaluation for the ADS-B Out rulemaking, the FAA used a cost range of $19,000 to $1.7 million for "large category turbojet airplanes." Given the added complexity and cost associated with integrating such capabilities into military systems, we set the baseline estimate for this study at $2 million. We used a per-unit value under the assumption that nonrecurring costs will be relatively small and that variation due to the number of aircraft will have a minor impact on the comparison between equipage and operations cost. The actual cost will vary for each aircraft depending on the level of CNS/ATM capability, the extent to which the ADS-B Out system is integrated into the avionics, and other characteristics specific to each platform. The approach taken in this study was to evaluate ADS-B Out cost-effectiveness based on a conservative estimate, noting that a modernization program that is cost-effective at this upgrade cost would have even greater cost-effectiveness if implemented at less expense. In cases in which the upgrade cost exceeds the CNS/ATM cost avoidance, we provide the break-even upgrade cost. In these instances, modernization is cost-effective only if it can be accomplished at this price.

Assumptions

In this section, we describe the key assumptions used in the analysis.

Fleet Modernization

A detailed engineering analysis examining installation issues was beyond the scope of this study. However, avionics upgrades generally do not involve structural modifications to an airframe (with the exception of adding antennas). As a result, such an upgrade does not change the performance characteristics of the aircraft and essentially involves replacing one or more components with updated line-replaceable units. These units must then be integrated into the remaining systems on the aircraft (e.g., flight control actuators, flight control position sensors, remaining avionics, wiring, data buses, antennas). For this analysis, we used installation schedules provided by the Air Force when they were available. Otherwise, we produced representative installation schedules based on historical modernization programs.

Cost Projection

The Air Force guidance for AoAs (AFMC, 2008) calls for an assessment of "peacetime" operating costs. We projected a future operations pattern based on the past ten years of operation, which included activity from the conflicts in Iraq and Afghanistan; consequently, the term *steady state* is used throughout this monograph to describe routine training and operational missions that comprise the regular flying hours.

Cost is defined in fiscal year (FY) 2011 dollars and broken down into two categories: fuel costs and nonfuel costs related to increased flying hours. We calculated fuel costs at $3 per gallon for jet fuel in the baseline case, but we also varied the fuel prices parametrically between $1 and $6 per gallon. Nonfuel costs related to increased flying hours include the Air Force Total Ownership Cost categories of support, temporary duty, repair parts, depot-level reparable, and depot repair.

We also used the discount rate of 2.3 percent, which is the real interest rate of a 30-year treasury bond published by the Office of Management and Budget for use in cost-effectiveness analyses (OMB, 2011).

Flight Delays Due to CNS/ATM Noncompliance

Unlike flight-level restrictions, delay amounts cannot be precisely specified in equipage mandates. This study used a representative flight delay of 14 minutes each time a noncompliant aircraft transits an ICAO region where a delay is a projected impact of noncompliance. This value is consistent with previous RAND CNS/ATM analyses and based on one year of U.S. domestic airline delays attributable to the National Airspace System (U.S. Department of Transportation, 2007). Rosello et al. (2009) provide a more detailed description of these delay assumptions.

Wartime Planning Scenarios

While there were specific planning scenarios that could have been used in this analysis, such as those that underlie the Mobility Capabilities and Requirements Study 2016, a U.S. Department of Defense evaluation of projected mobility capability improvements through 2016, it was necessary to generalize the results to keep this study unclassified. The scenarios described earlier in this chapter bound the potential change in existing wartime capability by considering a range of deployment distances and regions.

We derived the average deployment payloads for these missions from previous RAND analyses, as well as the Joint Flow and Analysis System for Transportation, a transportation analysis model used by the U.S. Transportation Command. The average payloads for the C-17 are 61,500 lb (over and outsize) and 72,000 lb (bulk). For the C-5, they are 123,000 lb (over and outsize) and 144,000 lb (bulk).

Aircraft Life

It is assumed that aircraft that are not currently slated for retirement will remain in service through 2040. This is based on guidance from the AMC Air, Space, and Mobility Operations Directorate's (AMC/A3's) Fuel Efficiency Office to maintain consistency with other recent AMC efficiency analyses, and it is also consistent with ongoing RAND research on intertheater airlift acquisition (Mouton et al., 2012).

CHAPTER FOUR

C-5 Modernization

Current Fleet Composition

As of this writing, there were 111 Lockheed C-5 Galaxy aircraft in the MAF fleet. Of these, 59 are C-5As, the first group produced for the U.S. Air Force. Another 47 are C-5Bs, which were built subsequent to the A models. These C-5Bs include prior C-5A improvements, plus additional modifications for improved reliability and maintainability. Two aircraft that have been modified to carry large payloads for the National Aeronautics and Space Administration are designated C models (AMC, 2009).

In 1998, AMC began the AMP to upgrade the CNS/ATM capabilities of these legacy aircraft. Later, the C-5's re-engining and reliability program oversaw the installation of GE F138-GE-100 engines, which produce more thrust and have better fuel efficiency than the original engines, and other system upgrades. Legacy aircraft that have undergone both of these programs are designated M models. There are currently only six C-5Ms in the fleet, but this number is expected to grow to 52 by 2017.

Figure 4.1 shows the current and projected C-5 fleet composition. The Air Force plans to retire 24 C-5As by 2014,[1] reducing the total fleet size to 79. All B and C models will be upgraded to M models by 2017, leaving 27 C-5As and 52 C-5Ms.[2]

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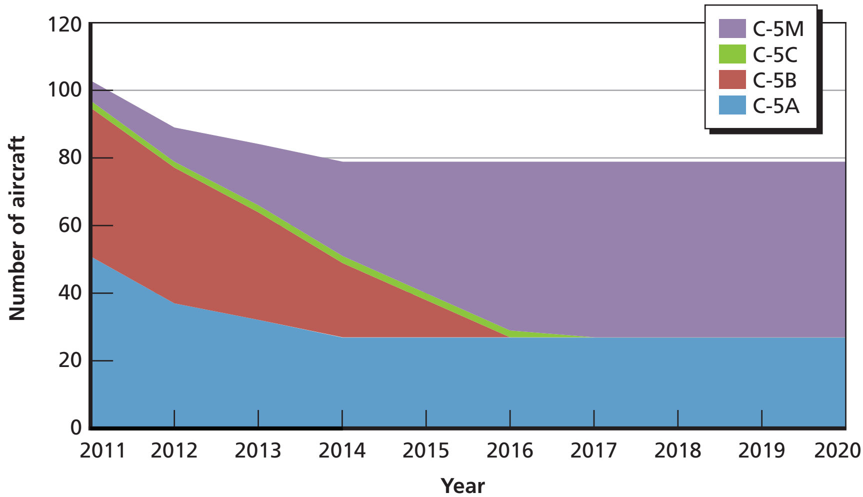
[1] This includes eight C-5A retirements in 2011, which is reflected in Figure 4.1.

[2] Currently, there is a statutory requirement to maintain 316 total strategic airlifters (C-5s and C-17s combined). The Air Force is seeking relief from Congress to bring the C-5 fleet

Figure 4.1
Projected Composition of the C-5 Fleet Through 2020



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Current and Planned Modernization Programs

The AMP addresses numerous CNS/ATM capability shortfalls in the C-5A/B fleet. Modernized aircraft comply with requirements for FANS-1/A, as well as performance-based navigation specifications down to RNAV-1 and RNP-0.3. While the program includes Mode S enhanced surveillance, it does not address ADS-B Out. Although not yet funded, there are plans to equip the entire fleet with ADS-B Out before the mandate takes effect in 2020. Table 4.1 summarizes the current C-5 capabilities and modernization programs. For each capability in the table, a check mark indicates compliance upon completion of the

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size to 79 for a total of 301 strategic mobility aircraft. In including a total of 79 C-5s in this study, we assumed that either this relief would be granted or the Air Force would actively fly only 79 C-5s. This approach serves to prevent the overstatement of cost avoidance from CNS/ATM noncompliance. The Air Force recently proposed retiring all of its C-5As. Since Congress has not yet responded to the proposal, PAF included the full C-5 fleet in these calculations.

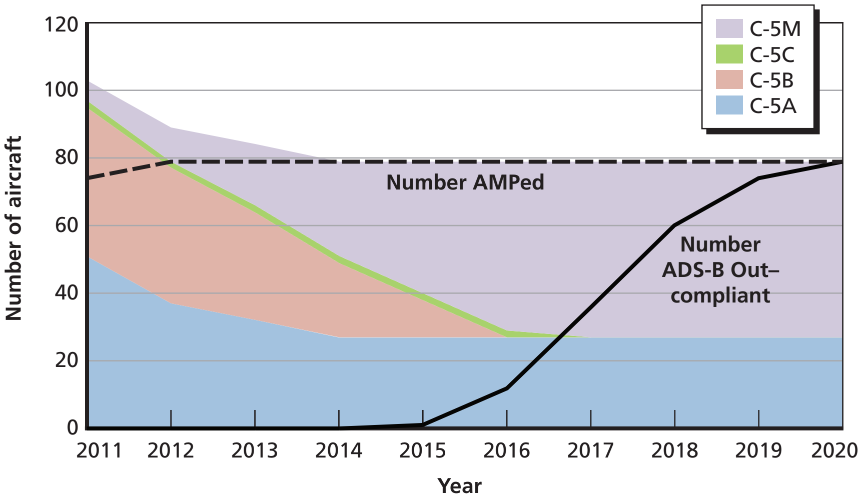
Table 4.1
Current C-5 Capabilities and Avionics Upgrade Programs

		Avionics Upgrade Programs	
Category	**Capability**	**AMP**	**ADS-B Out**
Communication	8.33-kHz VHF	Existing capability	
	CPDLC/FANS	√	
	SATCOM data link	√	
	SATCOM voice	√	
	VHF data link (VDL Mode 2)	X	X
Navigation	RNAV-1 (PRNAV)	√	
	RNAV-2 (U.S. RNAV)	√	
	RNP-4 (oceanic/remote)	√	
	RNP-0.3/1/2	√	
	RVSM	Existing capability	
Surveillance	ADS-B Out		√
	Mode S enhanced surveillance	√	

corresponding modernization program and an "X" identifies capabilities that will not be addressed by any planned programs.

Figure 4.2 shows the projected modernization path for the C-5 fleet through 2020, the year in which the entire fleet should be upgraded according to current plans. As of this writing, all but five aircraft that will remain in the fleet have undergone AMP, which is to be completed by the end of 2012. ADS-B Out equipage is assumed to begin in 2014 and be complete by 2020, when the mandate takes effect. Although there are no plans to equip the C-5 with a VDL Mode 2 data link, the aircraft will be exempt from the European Link 2000+ mandate as a result of its FANS-1/A equipage. Thus, there is no foreseeable impact on C-5 operations.

Figure 4.2
Projected Modernization Path for the C-5 Fleet Through 2020



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Operating Cost Avoidance from CNS/ATM Modernization

We used the flying pattern represented by the GDSS data set and supplemented with the representative training flight profile (see Appendix B) as the baseline for C-5 steady-state mobility operations through 2040. In this section, we present the results based on the analytical approach described in Chapter Three.

If the C-5 AMP continues as planned, $56 million in steady-state operating costs will be avoided through 2040. This value represents the marginal cost avoidance that would result from upgrading the remaining non-AMPed aircraft. Accounting for the $46 million in upgrade costs remaining in the program, completing AMP will lead to a net cost avoidance of $10 million, making the remaining program cost-effective based on steady-state CNS/ATM cost avoidance *alone*. (The additional value of maintaining wartime operational effectiveness is examined later in this chapter; other potential benefits, such as improved reliability and maintainability, were beyond the scope of this study but would also increase cost-effectiveness.)

Similarly, it is cost-effective to modernize for compliance with the 2020 ADS-B Out mandate that has already been passed into law in the United States. While equipping the entire fleet for ADS-B Out would cost approximately $136 million, the resulting cost avoidance would be $1.19 billion, netting almost $1.06 billion in cost avoidance. These results are summarized in Table 4.2.[3]

Figures 4.3 and 4.4 show how the cost avoidance from CNS/ATM compliance varies from these baseline values under different assumptions about the price of fuel and payload weights. Figure 4.5 provides a yearly breakdown of the cumulative cost avoidance for each modernization path.

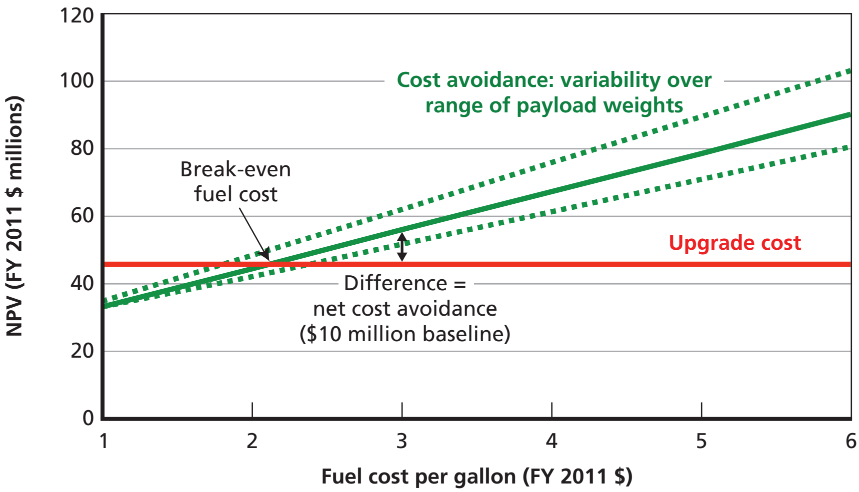
AMP is almost complete, with only $46 million in upgrade costs remaining in the program. Figure 4.3 shows the operating costs that would be avoided by completing the program. The magnitude of those costs (beyond the $21 million nonfuel cost component due to increased flying hours) depends on the price of fuel and steady-state payload weights, but the cost avoidance exceeds upgrade costs for fuel prices around $2 per gallon and higher.

Table 4.2
Summary of Net Present Value of C-5 Modernization Paths

	NPV (FY 2011 $ millions)		
Modernization Program	**CNS/ATM Cost Avoidance**	**Upgrade Cost**	**Net Cost Avoidance**
AMP	56	46	10
ADS-B Out	1,191	136	1,055

[3] The December 2009 Selected Acquisition Report (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2010a) lists a total procurement funding level of $838.1 million for the C-5 AMP. This includes 90 units at an average unit procurement cost of $9.3 million. There is no ongoing ADS-B Out modernization program for the C-5. As detailed in Chapter Three, we used a conservative unit procurement cost estimate of $2 million for all aircraft included in the study.

Figure 4.3
C-5 Cost Avoidance Through 2040 Resulting from Completing AMP as a Function of Fuel Cost and Payload Weight



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Current plans call for the full compliance of the C-5 fleet with ADS-B Out by the time it is mandated in 2020. Figure 4.4 illustrates the importance of following through with these plans. Modernization is cost-effective under any assumption and leads to substantial cost avoidance. The nonfuel cost component due to increased flying hours is $487 million.

Figure 4.5 breaks down the cost avoidance associated with CNS/ATM modernization by year, showing the cumulative cost avoidance in each year from 2011 through 2040. All costs are in FY 2011 dollars and assume a constant $3 per gallon fuel price. The upgrade costs for compliance are repeated in the figure for comparison. For cost-effective modernization programs, the year in which the cumulative cost avoidance exceeds the upgrade cost is the break-even year. This occurs around 2021 for ADS-B Out and 2034 for AMP.

Figure 4.4
C-5 Cost Avoidance Through 2040 Resulting from ADS-B Out Modernization as a Function of Fuel Cost and Payload Weight

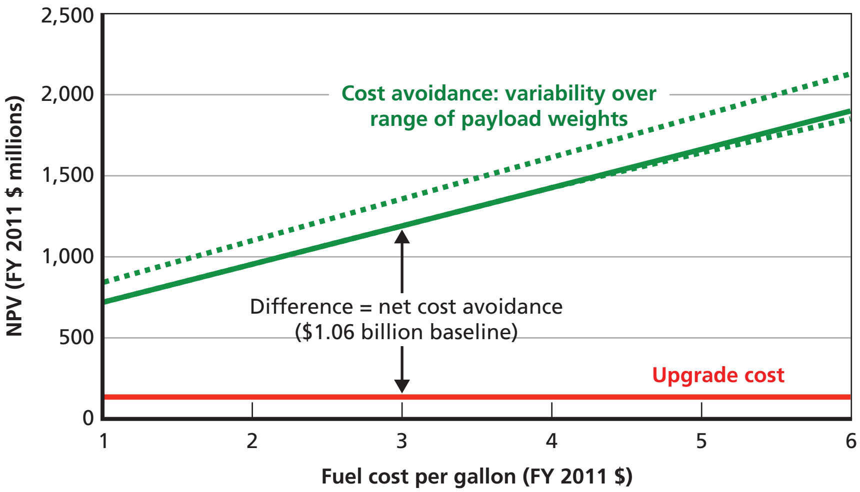

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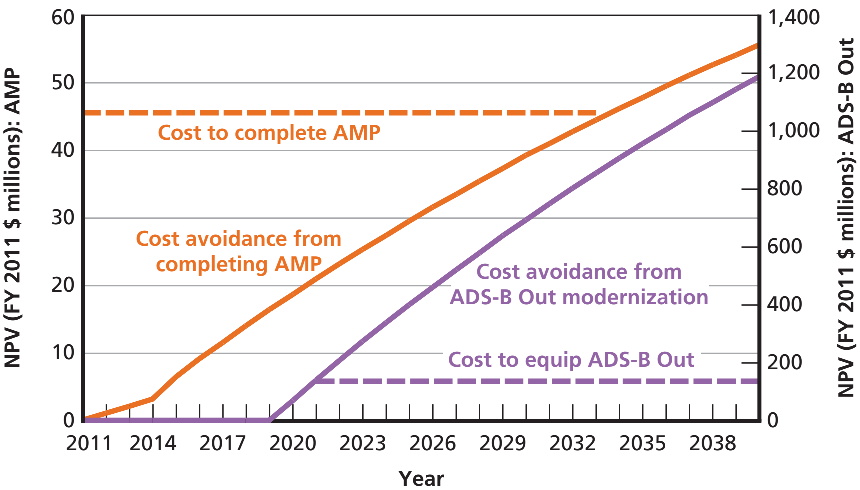
Figure 4.5
Yearly Cumulative Cost Avoidance Associated with C-5 CNS/ATM Compliance



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Operational Benefits from CNS/ATM Modernization

The strategic airlifter wartime mission involves the deployment of forces from bases in the United States to a theater of operations. This typically requires a large number of sorties transiting great distances over the course of several weeks or months. While national airspace authorities can grant waivers to military aircraft that do not comply with CNS/ATM mandates, accommodating them as air traffic systems allow, the disruptive potential of large, enduring deployments through busy airspace highlights the importance of modernization for unrestricted airspace access and unconstrained global reach.

For this study, we assumed that noncompliant aircraft would face the same penalties imposed for steady-state operations when operating outside the theater of operations during wartime. Strategic airlifters do most of their wartime flying outside of the theater and would be affected by CNS/ATM mandates, reducing their wartime effectiveness. Modernization to comply with these mandates would prevent operating restrictions, maintaining current effectiveness.

Effects of Noncompliance on Wartime Effectiveness

We examined the impact of CNS/ATM noncompliance on the wartime mission for the same modernization programs considered in the steady-state operating portion of the study: AMP and ADS-B Out modernization. Table 4.3 summarizes the results, which are detailed in the following sections.

The current modernization path (completing AMP and ADS-B Out modernization) leads to compliance with all mandates that affect

Table 4.3
Range of Yearly C-5 Wartime Capability Shortfall That Would Be Avoided by Modernization

Modernization Program	Range of Yearly Shortfall (no. of aircraft)
AMP	0.1–0.2
ADS-B Out	3.2–5.4

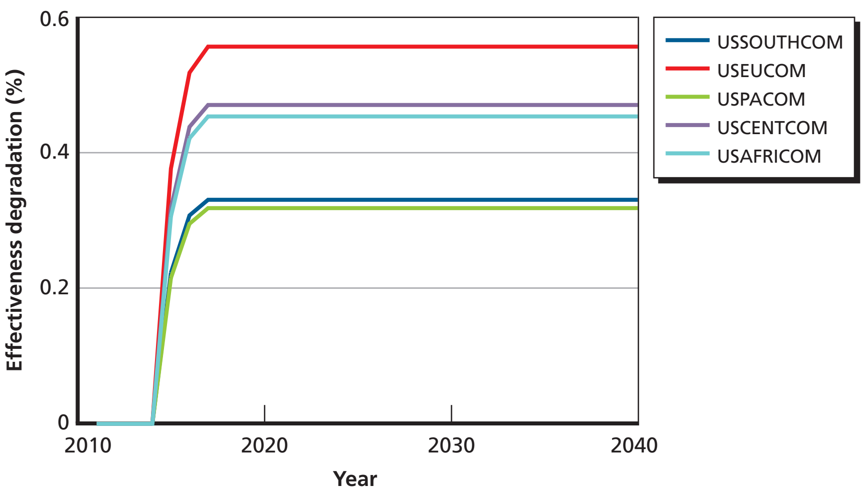
the wartime mission; consequently, the C-5 would retain full wartime effectiveness.[4]

Wartime Impact of Completing AMP

Figure 4.6 shows the degradation of the C-5A/B/C fleet's wartime effectiveness that would be avoided by completing AMP. (The C-5M fleet would not be affected, as those aircraft have already undergone the AMP upgrade.) The impacts of noncompliance begin in 2015, when the RNAV mandates take effect in North America, and peak two years later, when the last M model conversions reduce the C-5A/B/C fleet size to 27 aircraft. The five noncompliant aircraft represent a larger portion of the smaller fleet in those years and, thus, a higher level of degradation for the fleet's effectiveness.

The effectiveness degradation shown in the figure can be translated into the number of additional C-5–equivalent aircraft needed

Figure 4.6
Degradation of C-5A/B/C Fleet Wartime Effectiveness Avoided by Completing AMP



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[4] While the C-5 lacks the capabilities required by the Link 2000+ implementing rule in Europe, it will be exempt from this mandate for its lifetime (as is any FANS-1/A-capable aircraft with an initial individual airworthiness certificate issued before January 1, 2014).

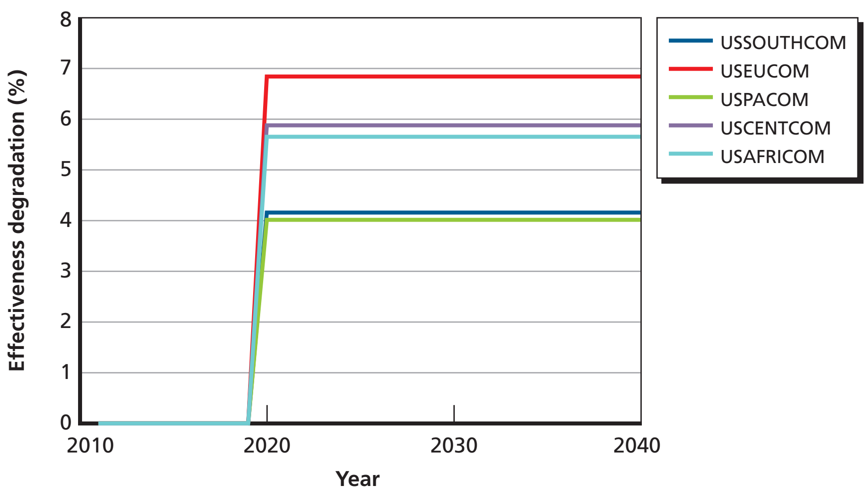
in each year to maintain the current wartime capability, which ranges from 0.1 to 0.2 starting in 2015.

Wartime Impact of Modernizing for ADS-B Out

Figure 4.7 shows the degradation of the C-5 fleet's wartime effectiveness that would be avoided by ADS-B Out modernization. Because no aircraft are currently equipped with this capability, the entire fleet will be affected when the mandate takes effect in 2020, including the M models.

The effectiveness degradation shown in the figure can be translated into the number of additional C-5–equivalent aircraft needed in each year to maintain the current wartime capability, which ranges from 3.2 to 5.4 starting in 2020.

Figure 4.7
Degradation of C-5A/B/C/M Fleet Wartime Effectiveness Avoided by ADS-B Out Modernization



RAND *MG1194-4.7*

Observations

Current and planned C-5 modernization programs are cost-effective, even based solely on the steady-state cost avoidance that results from compliance with CNS/ATM mandates; furthermore, the wartime effectiveness of the fleet will degrade if these programs are not completed. The most substantial net cost avoidance results from ADS-B Out modernization, underscoring the importance of following through with plans to fully upgrade the fleet with this capability prior to the 2020 mandate.

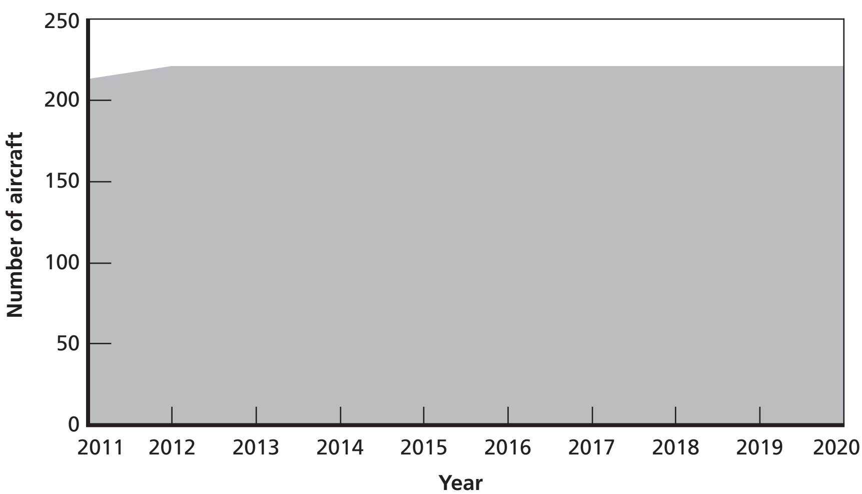
CHAPTER FIVE

C-17 Modernization

Current Fleet Composition

There are currently 213 Boeing C-17 Globemaster III aircraft in the MAF fleet. The Air Force plans to complete its acquisition of the C-17 in 2012, when the fleet reaches 221 aircraft. Figure 5.1 shows the projected fleet size through 2020.[1]

Figure 5.1
Projected Size of the C-17 Fleet Through 2020



RAND *MG1194-5.1*

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1 Based on C-17 system program office modification plans shared during a meeting on March 9, 2011.

Current and Planned Modernization Programs

There are two ongoing C-17 avionics modernization programs that will affect access to worldwide airspace. The C-17 GATM/RNP-1 program, which is part of a larger effort to retrofit aircraft up to a Block 17 configuration, addresses the aircraft's navigation capability, while the CNS/ATM Phase I effort addresses its surveillance capability.

The GATM/RNP-1 program provides required navigation performance capability down to RNP-0.3. More than half of the aircraft in the C-17 fleet already have these capabilities, because they either came off the production line in the Block 17 configuration or have already been retrofitted. Fleet-wide modification should be complete in 2016.

The CNS/ATM Phase I effort focuses primarily on surveillance modernization and will provide the entire fleet with the ADS-B Out capability. This program is slated to begin installation in 2016 and should be complete in 2020, the year in which the mandate takes effect in the United States.

Table 5.1 summarizes the C-17's current capabilities and modernization programs. For each capability in the table, a check mark indicates compliance upon completion of the corresponding modernization program and an "X" identifies capabilities that will not be addressed by any planned programs.

Figure 5.2 shows the projected modernization path for the C-17 fleet through 2020, the year by which all upgrades should be complete.[2]

[2] The FY 2009 President's Budget lists a total procurement funding of $216.5 million for the C-17 GATM/RNP-1 program. This includes 152 units at an average unit procurement cost of $1.4 million (Executive Office of the President, 2008). There is no ongoing ADS-B Out modernization program for the C-17. As detailed in Chapter Three, we used a conservative unit procurement cost estimate of $2 million for all aircraft included in the study.

Table 5.1
Current C-17 Capabilities and Avionics Upgrade Programs

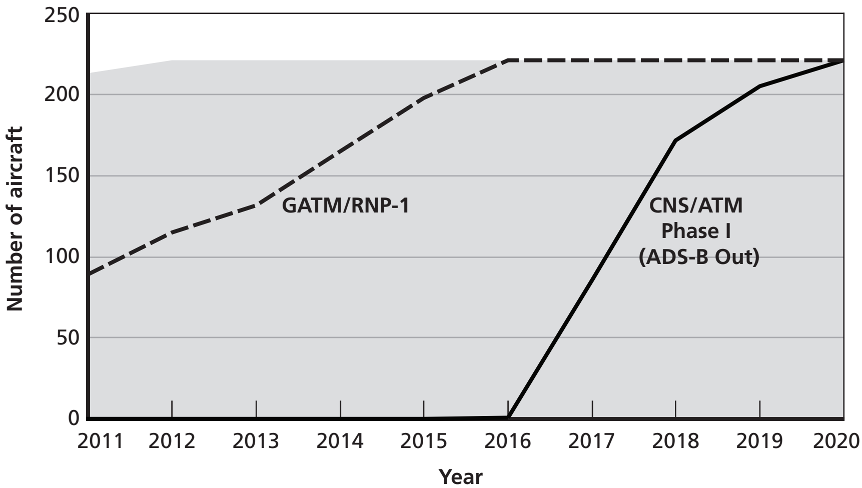
		Avionics Upgrade Programs	
Category	**Capability**	**GATM/RNP-1**	**CNS/ATM Ph I**
Communication	8.33-kHz VHF	Existing capability	
	CPDLC/FANS	Existing capability	
	SATCOM data link	Existing capability	
	SATCOM voice	Existing capability	
	VHF data link (VDL Mode 2)	X	X
Navigation	RNAV-1 (PRNAV)	Existing capability	
	RNAV-2 (U.S. RNAV)	Existing capability	
	RNP-4 (oceanic/remote)	√	
	RNP-0.3/1/2	√	
	RVSM	Existing capability	
Surveillance	ADS-B Out		√
	Mode S enhanced surveillance	√	

Operating Cost Avoidance from CNS/ATM Modernization

We used the flying pattern in the GDSS data set, supplemented by the representative training flight profile (see Appendix B), as the baseline for C-17 steady-state mobility operations through 2040. In this section, we present the results based on the analytical approach described in Chapter Three.

If the GATM/RNP-1 program continues as planned, $361 million in steady-state operating costs will be avoided through 2040. This value represents the marginal cost avoidance that would result from upgrading the remaining unmodified aircraft. Accounting for the $142 million in upgrade costs remaining in the program, completing the GATM/RNP-1 upgrades will lead to a net cost avoidance of $219 million, making the remaining program cost-effective based

Figure 5.2
Projected Modernization Path for the C-17 Fleet Through 2020



RAND *MG1194-5.2*

on steady-state CNS/ATM cost avoidance *alone*. (The additional value of maintaining wartime operational effectiveness is examined later in this chapter; other potential benefits, such as improved reliability and maintainability, were beyond the scope of this study but would also increase cost-effectiveness.)

Similarly, it is cost-effective to modernize for compliance with the 2020 ADS-B Out mandate that has already been passed into law in the United States. While equipping the entire fleet for ADS-B Out would cost approximately $390 million, the resulting cost avoidance would be $3.67 billion, netting approximately $3.28 billion in cost avoidance for the CNS/ATM Phase I program. These results are summarized in Table 5.2.

Figures 5.3 and 5.4 show how the cost avoidance from CNS/ATM compliance varies from these baseline values under different assumptions. Chapter Three described the assumptions underlying each case in greater detail. Figure 5.5 provides a yearly breakdown of the cumulative cost avoidance for each modernization path.

GATM/RNP-1 is in progress, with $142 million in upgrade costs remaining in the program. Figure 5.3 shows the additional operating

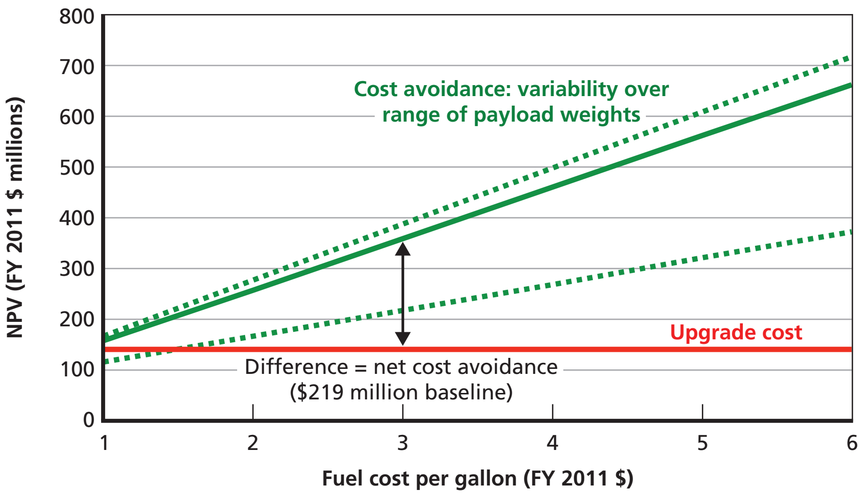
Table 5.2
Summary of Net Present Value of C-17 Modernization Paths

	NPV (FY 2011 $ millions)		
Modernization Program	CNS/ATM Cost Avoidance	Upgrade Cost	Net Cost Avoidance
GATM/RNP-1	361	142	219
CNS/ATM Phase I (ADS-B Out)	3,666	390	3,276

costs that would be incurred if the program were not completed. The magnitude of those penalties (beyond the $57 million nonfuel cost component due to increased flying hours) depends on the price of fuel and steady-state payload weights, but the cost of modernization is lower than the cost of noncompliance for fuel prices as low as $1 per gallon.

Current plans call for the C-17 fleet's full compliance with ADS-B Out by the time it is mandated in 2020 as part of the CNS/ATM I program. Figure 5.4 illustrates the importance of following through with these plans. Modernization is cost-effective under any assumptions and

Figure 5.3
C-17 Cost Avoidance Through 2040 Resulting from Completing GATM/RNP-1 as a Function of Fuel Cost and Payload Weight



RAND *MG1194-5.3*

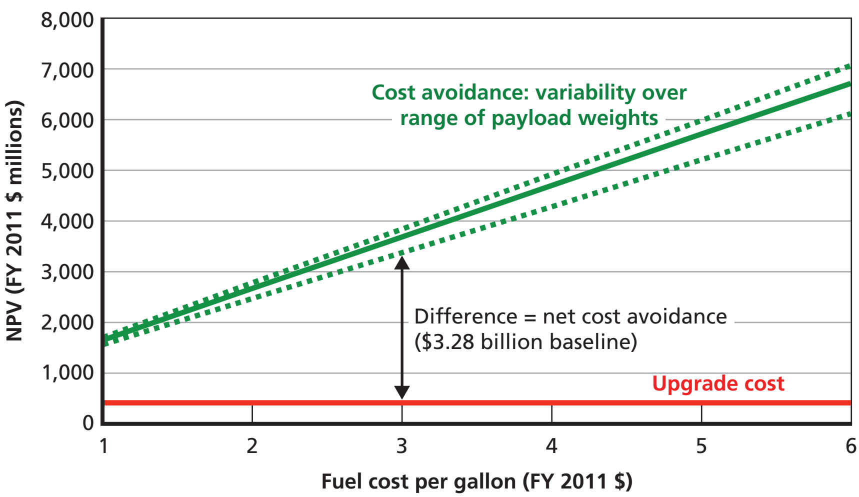
leads to substantial cost avoidance. The nonfuel cost component due to increased flying hours is $613 million.

Figure 5.5 breaks down the cost avoidance associated with CNS/ATM compliance by year, showing the cumulative cost avoidance in each year from 2011 through 2040. All costs are in FY 2011 dollars and assume a constant $3 per gallon fuel price. The upgrade costs of compliance are repeated in the figure for comparison. For cost-effective modernization programs, the year in which the cumulative cost avoidance exceeds the upgrade cost is the break-even year. This occurs around 2021 for ADS-B Out and 2023 for GATM/RNP-1.

Operational Benefits from CNS/ATM Modernization

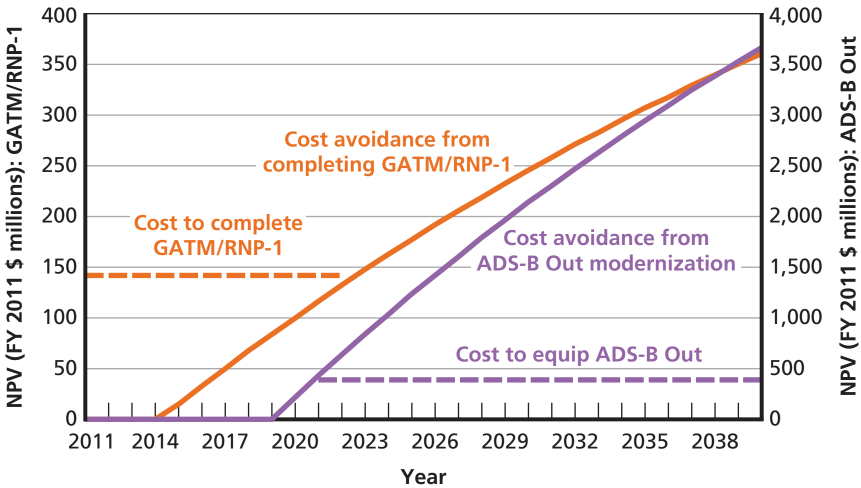
As described earlier, strategic airlifters do most of their wartime flying outside of the theater and would be affected by CNS/ATM mandates, which would reduce their wartime effectiveness. Modernization to

Figure 5.4
C-17 Cost Avoidance Through 2040 Resulting from ADS-B Out Modernization as a Function of Fuel Cost and Payload Weight



RAND *MG1194-5.4*

Figure 5.5
Yearly Cumulative Cost Avoidance Associated with C-17 CNS/ATM Compliance



RAND *MG1194-5.5*

comply with these mandates would prevent operating restrictions, maintaining current effectiveness.

Effects of Noncompliance on Wartime Effectiveness

We examined the impact of CNS/ATM noncompliance on the wartime mission for the same modernization programs considered in the steady-state operating portion of the study: GATM/RNP-1 and CNS/ATM Phase I (ADS-B Out). Table 5.3 summarizes the results, which are detailed in the following sections. The current modernization path leads to compliance with all mandates;[3] consequently, the C-17 would retain full wartime effectiveness.

[3] While the C-17 lacks the capabilities required by the Link 2000+ implementing rule in Europe, it will be exempt from this mandate for its lifetime (as is any FANS-1/A-capable aircraft with an initial individual airworthiness certificate issued before January 1, 2014).

Table 5.3
Range of Yearly C-17 Wartime Capability Shortfall That Would Be Avoided by Modernization

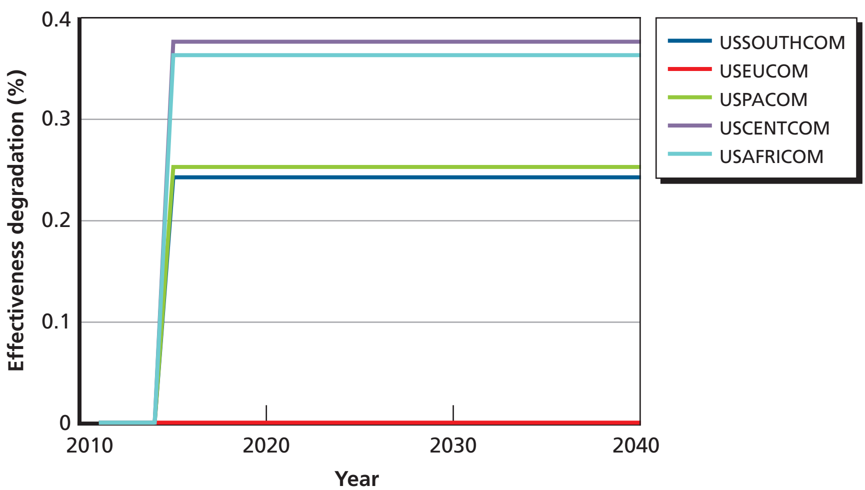
Modernization Program	Range of Yearly Shortfall (no. of aircraft)
GATM/RNP-1	0–0.8
CNS/ATM Phase I (ADS-B Out)	8.3–14.0

Wartime Impact of Completing GATM/RNP-1

Figure 5.6 shows the degradation of the C-17 fleet's wartime effectiveness that would be avoided by completing GATM/RNP-1. Degradation occurs in 2015, primarily as a result of the impact of the North American mandate to access airspace above FL290.

The effectiveness degradation shown in the figure can be translated into the number of additional C-17–equivalent aircraft needed in each year to maintain the current wartime capability, which ranges from 0 to 0.8 starting in 2015.

Figure 5.6
Degradation of the C-17 Fleet Wartime Effectiveness Avoided by Completing GATM/RNP-1



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Wartime Impact of Modernizing for CNS/ATM Phase I (ADS-B Out)

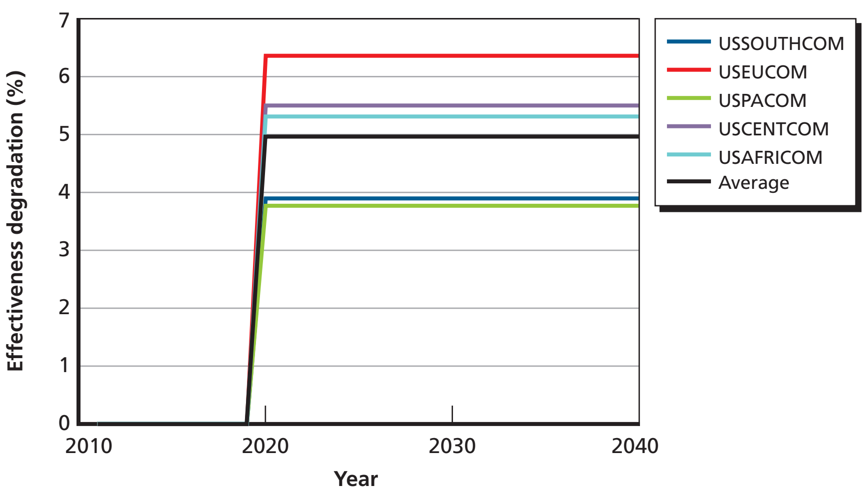
Figure 5.7 shows the degradation of the C-17 fleet's wartime effectiveness that would be avoided by ADS-B Out modernization. Because no aircraft are currently equipped with this capability, the entire fleet would be affected when the mandate takes effect in 2020.

The effectiveness degradation shown in the figure can be translated into the number of additional C-17–equivalent aircraft needed in each year to maintain the current wartime capability, which ranges from 8.3 to 14.0 starting in 2020.

Observations

Current and planned C-17 modernization programs are cost-effective, even based solely on the steady-state cost avoidance that results from compliance with CNS/ATM mandates; furthermore, the wartime effectiveness of the fleet will degrade if these programs are not completed. The most substantial net cost avoidance results from ADS-B

Figure 5.7
Degradation to C-17 Fleet Wartime Effectiveness Avoided by CNS/ATM Phase I (ADS-B Out) Modernization



RAND *MG1194-5.7*

Out modernization, underscoring the importance of following through with plans to fully upgrade the fleet with this capability prior to the 2020 mandate.

CHAPTER SIX

KC-135 Modernization

Current Fleet Composition

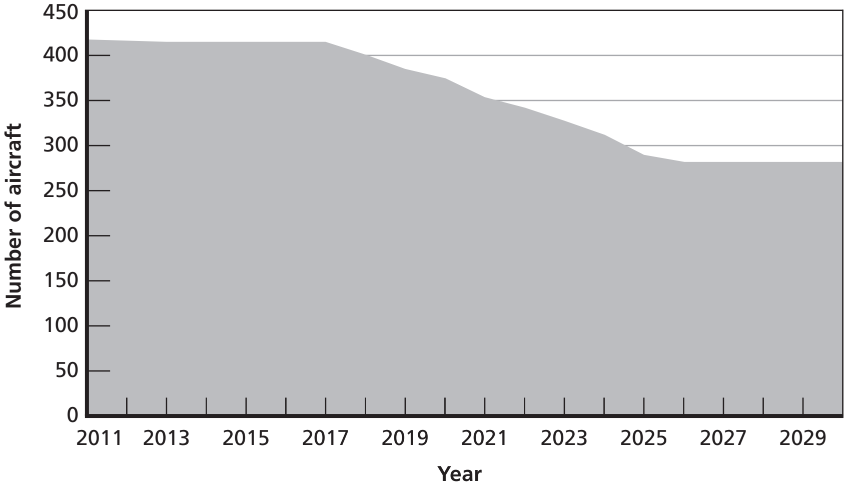
There are currently 418 Boeing KC-135 Stratotankers in the MAF fleet. Delivered to the Air Force from the mid-1950s to the mid-1960s, they are the oldest MAF aircraft. The fleet consists of 364 KC-135R and 54 KC-135Ts (formerly KC-135Q). The latter have the unique capability to carry different fuels in their wing and body tanks (Air Force Association, 2011); however, for this analysis of CNS/ATM capabilities, the two are treated as the same. A few of the aircraft are scheduled to be converted to other, non-tanker variants over the next few years, bringing the total down to 415. The KC-135 fleet size will remain at 415 until the introduction of the new KC-46A, which will start to replace the Stratotankers in the mid- to late 2010s. The projected fleet size through 2030 is shown in Figure 6.1.

Current and Planned Modernization Programs

Despite being the oldest MAF aircraft, the KC-135 has the most advanced avionics. The fleet-wide Pacer Compass Radar and GPS (CRAG) (Block 30) upgrade program was completed in 2004, and the GATM (Block 40) avionics upgrade was completed in 2011.

Although it is not yet funded, there are plans to equip the entire fleet with ADS-B Out before the mandate takes effect in 2020. Table 6.1 summarizes the KC-135's current capabilities and modernization programs. For each capability in the table, a check mark indi-

Figure 6.1
Projected KC-135 Fleet Size Through 2030



RAND *MG1194-6.1*

cates compliance upon completion of the corresponding modernization program.

With the completion of ongoing modernization in 2011, the KC-135 will comply with all avionics mandates included in this study except ADS-B Out. There are plans for ADS-B Out modernization, but no installation schedule has been established. This analysis assumes that installation would begin in 2012, with 40 aircraft undergoing modernization each year until completion in 2019. Figure 6.2 shows this projected modernization path.

Operating Cost Avoidance from CNS/ATM Modernization

We used the flying pattern in the GDSS data set, supplemented by the representative training flight profile (see Appendix B), as the baseline for KC-135 steady-state mobility operations through 2040. In this section, we present the results based on the analytical approach described in Chapter Three.

Table 6.1
Current KC-135 Capabilities and Avionics Upgrade Programs

Category	Capability	Avionics Upgrade Programs: GATM (Block 40)	Avionics Upgrade Programs: ADS-B Out
Communication	8.33-kHz VHF	Existing capability	
	CPDLC/FANS	√	
	SATCOM data link	√	
	SATCOM voice	√	
	VHF data link (VDL Mode 2)	√	
Navigation	RNAV-1 (PRNAV)	√	
	RNAV-2 (U.S. RNAV)	√	
	RNP-4 (oceanic/remote)	√	
	RNP-0.3/1/2	√	
	RVSM	Existing capability	
Surveillance	ADS-B Out		√
	Mode S enhanced surveillance	Partial	

It is cost-effective to modernize for compliance with the 2020 ADS-B Out mandate that has already been passed into law in the United States. While equipping the entire fleet for ADS-B Out would cost approximately $504 million, the resulting cost avoidance would be $1.95 billion, netting approximately $1.45 billion in cost avoidance. No other modernization programs are necessary at this time for compliance with existing or planned CNS/ATM mandates that could affect airspace access. These results are summarized in Table 6.2.[1]

Figure 6.3 shows how the cost avoidance from CNS/ATM compliance varies from this baseline value under different assumptions. Chapter Three described the assumptions underlying each case in

[1] There is no ongoing ADS-B Out modernization program for the KC-135. As detailed in Chapter Three, a conservative unit procurement cost estimate of $2 million was used for all aircraft included in this study.

Figure 6.2
Projected Modernization Path for the KC-135 Fleet Through 2030

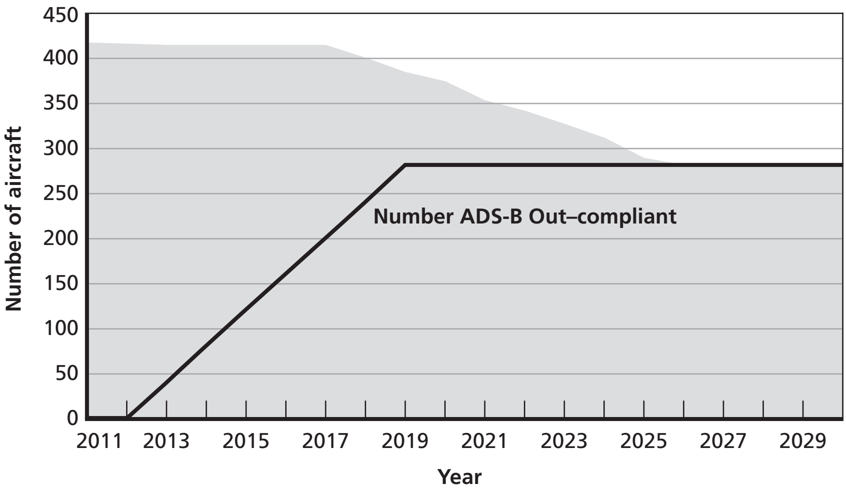


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Table 6.2
Summary of Net Present Value of KC-135 Modernization Paths

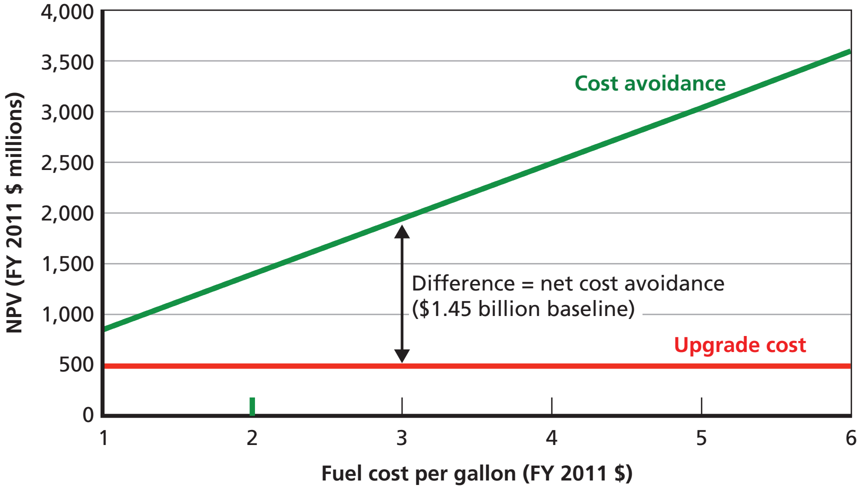
	NPV (FY 2011 $ millions)		
Modernization Program	**CNS/ATM Cost Avoidance**	**Upgrade Cost**	**Net Cost Avoidance**
ADS-B Out	1,952	504	1,448

greater detail. The nonfuel cost component due to increased flying hours is $321 million. Figure 6.4 provides a yearly breakdown of the cumulative cost avoidance due to ADS-B Out modernization.

For the KC-135, varying the payload weight has little effect on the penalties of noncompliance because a majority of these missions involve taking off and landing at the same base with less variation in fuel load. The penalties are conservative because the aircraft were assumed to carry as much fuel as allowed on each sortie, putting them at the maximum weight, resulting in the smallest impact from noncompliance.

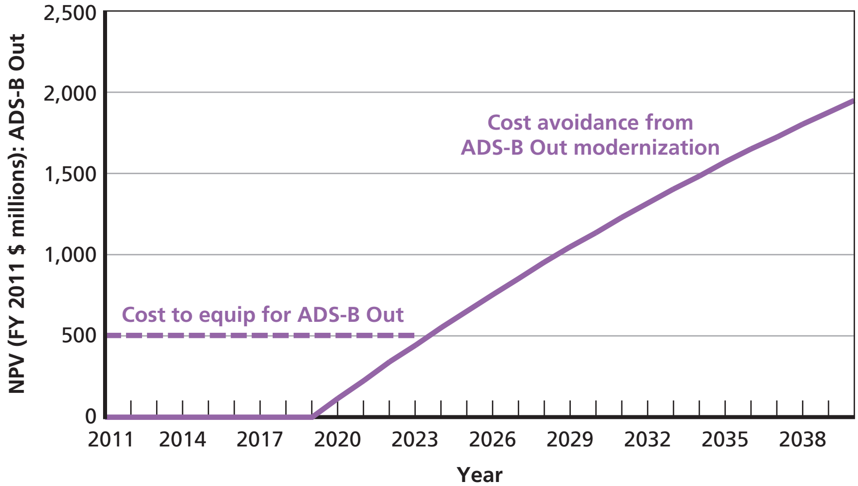
Figure 6.4 breaks down the cost avoidance associated with CNS/ATM compliance in each year from 2011 through 2040. All costs are

Figure 6.3
KC-135 Cost Avoidance Through 2040 Resulting from ADS-B Out Modernization as a Function of Fuel Cost



RAND *MG1194-6.3*

Figure 6.4
Yearly Cumulative Cost Avoidance Associated with KC-135 CNS/ATM Compliance



RAND *MG1194-6.4*

in FY 2011 dollars and assume a constant $3 per gallon fuel price. The upgrade costs of compliance are repeated in the figure for comparison. For cost-effective modernization programs, the year in which the cumulative cost avoidance exceeds the upgrade cost is the break-even year. This occurs around 2024 for ADS-B Out.

Operational Benefits from CNS/ATM Modernization

It is unlikely that the KC-135's wartime missions would be affected by CNS/ATM noncompliance, primarily because the Stratotanker is largely compliant with worldwide mandates that affect access to airspace. As discussed previously, ADS-B Out modernization is planned for the KC-135, but the upgrade has not yet been installed. When we examined the impact of ADS-B Out noncompliance on wartime tanker missions, we found none, either because the missions were of such high priority that compliance with ADS-B Out would have been waived or because the missions would be conducted outside of airspace that requires ADS-B Out. More explanation for each of the tanker warfighting missions follows.

Warfighting Missions

Estimating the warfighting impact of KC-135 noncompliance with ADS-B Out required determining which specific missions would be affected based on consideration of the wartime scenario and judgment about whether ATM mandates would be enforced. There is no certainty about these future conditions; rather, assessments are based on judgment and experience. We discussed these issues with many informed military and political experts, but the ultimate judgment is that of the authors. We analyzed seven broad tanker missions, and none is expected to be affected by CNS/ATM mandates. These missions are homeland defense, strategic deterrence and global strike, employment, deployment, air bridge, national reserve, and global strike. Definition and representation of these missions are based on air mobility operations doctrine found in Joint Publication 3-17 (U.S. Joint Chiefs of Staff, 2009), as well as the RAND KC-X AoA (Stillion, Orletsky, and Fitzmartin, 2005) and the RAND KC-10 modernization study (Rosello et al., 2009).

Tanker Missions for Which ADS-B Out Compliance Would Be Waived

The homeland defense, strategic deterrence and global strike, and employment missions would not be affected by CNS/ATM mandates. *Homeland defense* refers to a scenario similar to that in the United States after the terrorist attacks of September 11, 2001, in which fighter combat air patrols would be in place over major U.S. cities and other critical locations. These patrols would require air refueling support and a high fuel state to engage any potential adversaries. In this situation, U.S. civil ATC authorities would likely grant waivers to tanker aircraft that are noncompliant to ensure national security.

Strategic deterrence and global strike refers to a large-scale nuclear strike mission. Given the gravity of conducting a massive nuclear strike against an enemy, compliance with U.S. ADS-B Out mandates would likely not be required for participating aircraft.

Employment missions would not be affected, since there are currently no planned ADS-B Out mandates outside of the United States and Australia. Furthermore, a country willing to base U.S. military aircraft would not likely restrict their operation during wartime by requiring compliance with civil air traffic mandates.

Tanker Missions Outside of Airspace Requiring ADS-B Out

The wartime tanker missions that could be affected by noncompliance with ADS-B Out include deployment, air bridge, national reserve, and global strike. However, these missions would most likely take place outside of the continental United States and thus would not be affected by noncompliance.

In the deployment mission, which involves escorting and refueling fighter aircraft in transit to an area of operation, fighter aircraft and tankers could rendezvous over coastal waters, eliminating or minimizing the amount of time spent in airspace that requires ADS-B Out.

For the missions that involve conducting a single air refueling offload to a large receiver—air bridge, global strike, and national reserve—the tankers would most effectively launch from coastal locations and conduct the actual refueling outside of airspace where ADS-B is mandated.

Observations

Even though the KC-135 is the oldest MAF aircraft, it has the most updated avionics of those included in this study. The Stratotanker has completed two avionics upgrade programs: Pacer CRAG in 2004 and GATM in 2011. With these upgrades, it is compliant with all but ADS-B Out, which is planned for installation later this decade. The increased steady-state operating costs that would result from noncompliance far exceed the cost of installing ADS-B Out, making the modernization program cost-effective based on CNS/ATM benefits alone. There would be no effect on the KC-135's wartime missions, either because the nature of the mission would trump compliance with CNS/ATM mandates or because the aircraft is already compliant with mandates that would have otherwise affected its wartime mission effectiveness.

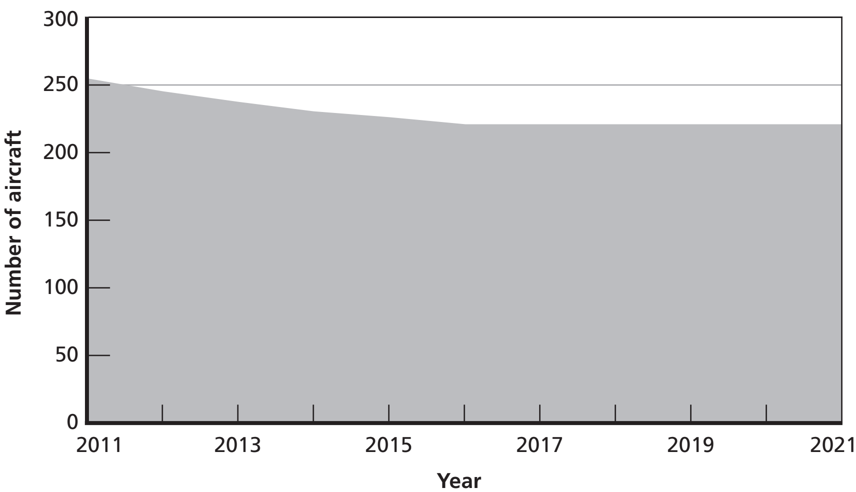
CHAPTER SEVEN

C-130H Modernization

Current Fleet Composition

There are currently 255 C-130H aircraft in the MAF fleet. Thirty-four are scheduled for retirement at a rate of five to ten per year until 2016, when 221 will remain. These aircraft will remain in the fleet, along with the newer J models, until their service life expires. Figure 7.1 shows the projected fleet composition through 2021.

Figure 7.1
Projected Composition of the C-130H Fleet Through 2021



RAND *MG1194-7.1*

Current and Planned Modernization Programs

The C-130 AMP was awarded to Boeing in 2001, with the first aircraft received for modification in 2005. The program includes an upgrade to a modern digital glass cockpit with six multifunction displays, pilot and co-pilot head-up displays, night-vision imaging system compatibility, and a modular, net-ready open-system architecture (Boeing Company, 2011). AMP addresses numerous CNS/ATM capability shortfalls in the C-130H fleet. Modernized aircraft will comply with requirements for CPDLC/FANS, VDL Mode 2, 8.33 kHz radio spacing, and performance-based navigation specifications down to RNAV-1 and RNP-0.3.[1] While the program does not address ADS-B Out, there are plans to equip the entire fleet with this surveillance capability around the time the mandate takes effect in 2020. Table 7.1 summarizes the C-130H's current capabilities and modernization programs. For each capability in the table, a check mark indicates compliance upon completion of the corresponding modernization program and an "X" identifies capabilities that will not be addressed by any planned programs.

Currently, only four aircraft have undergone the AMP upgrades, which should be complete by 2020.[2] ADS-B Out equipage, while not yet funded, is expected to begin around 2015 and to be complete by 2021. Figure 7.2 shows this projected modernization path for the C-130H.

Operating Cost Avoidance from CNS/ATM Modernization

We used the flying pattern in the GDSS data set, supplemented by the representative training flight profile (see Appendix B), as the baseline for C-130H steady-state mobility operations through 2040. In this sec-

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1 According to the system program office, while AMP may provide RNP-0.3 capability, the current plan is to only certify the aircraft down to the RNP-1 specification.

2 The Air Force recently proposed cancellation of AMP in favor of a less expensive CNS/ATM modernization program. This decision is consistent with the findings presented here, which indicate that this program is not cost-effective based on the cost avoidance associated with CNS/ATM compliance.

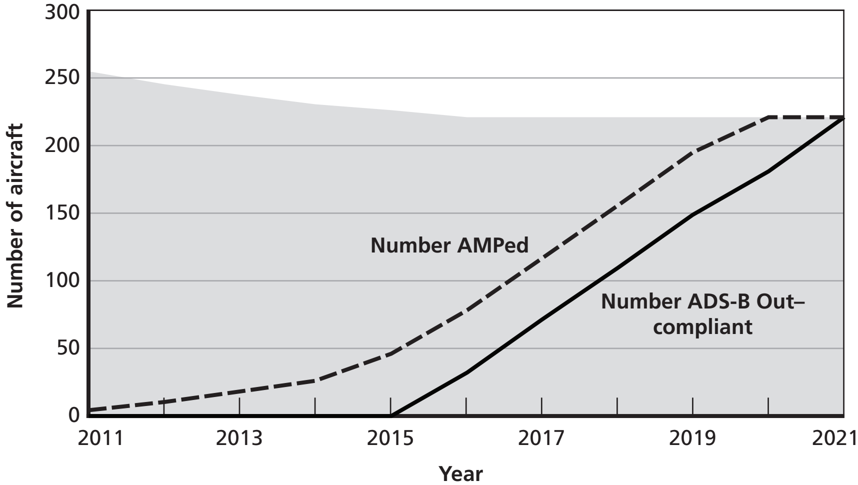
Table 7.1
Current C-130H Capabilities and Avionics Upgrade Programs

		Avionics Upgrade Programs	
Category	**Capability**	**AMP**	**ADS-B Out**
Communication	8.33-kHz VHF	√	
	CPDLC/FANS	√	
	SATCOM data link	√	
	SATCOM voice	√	
	VHF data link (VDL Mode 2)	√	
Navigation	RNAV-1 (PRNAV)	√	
	RNAV-2 (U.S. RNAV)	√	
	RNP-4 (oceanic/remote)	√	
	RNP-0.3/1/2	√	
	RVSM	X	X
Surveillance	ADS-B Out		√
	Mode S enhanced surveillance	√	

tion, we present the results based on the analytical approach described in Chapter Three.

If AMP is continued as planned, $60 million in additional steady-state operating costs will be incurred due to noncompliance with CNS/ATM mandates, since the program is late to meet several mandates. Once aircraft are modernized, they will avoid these operating costs. The NPV of CNS/ATM cost avoidance through 2040 is $280 million. This value represents the marginal cost avoidance that would result from upgrading the remaining non-AMPed aircraft. Accounting for the $3.55 billion in upgrade costs remaining in the program, completing the AMP upgrades will lead to a net cost of $3.27 billion, meaning that the remaining program is not cost-effective based on steady-state CNS/ATM cost avoidance *alone*. There are additional potential benefits to this program, the examination of which was beyond the scope of this study. Examples include decreased manpower costs due to elimi-

Figure 7.2
Projected Modernization Path for the C-130H Fleet Through 2021



RAND *MG1194-7.2*

nating the navigator, fleet commonality, and improved reliability and maintainability.

Since these aircraft tend to cruise at lower altitudes than the larger aircraft included in the study, the altitude restrictions associated with ADS-B Out noncompliance have less impact, and the cost avoidance from ADS-B Out modernization is less substantial. While equipping the entire fleet for ADS-B Out would cost approximately $373 million, the resulting cost avoidance would be only $329 million. These results are summarized in Table 7.2. For ADS-B Out modernization to be cost-effective, the upgrade cost would need to be $1.5 million or less per aircraft *or* fuel would need to reach and remain at or above $3.50 per gallon.[3]

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[3] The June 2010 Selected Acquisition Report (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2010b) shows total procurement funding of $4.1 billion for the C-130 AMP. This includes 218 units at an average unit procurement cost of $18.8 million. There is no ongoing ADS-B Out modernization program for the C-130. As detailed in Chapter Three, a conservative unit procurement cost estimate of $2 million was used for all aircraft included in this study.

Table 7.2
Summary of Net Present Value of C-130H Modernization Paths

	NPV (FY 2011 $ millions)			
Modernization Program	CNS/ATM Cost Avoidance	Upgrade Cost	Net Cost Avoidance	Break-Even Cost
AMP	280	3,549	–3,269	NA
ADS-B Out	329	373	–44	$3.50/gal fuel or $1.5 million upgrade

ADS-B Out compliance will be required to access Class B and C airspace, and failure to modernize would restrict access to many of the busiest airports in the country. This includes several joint civil-military bases where C-130s are currently stationed. If these aircraft must be rebased due to ADS-B Out noncompliance, the case for modernization would be strengthened, since the upgrade would result in additional cost avoidance. An analysis of the effects on basing was beyond the scope of this study, but any C-130H costs that result from ADS-B Out noncompliance and exceed $44 million would make modernization cost-effective.[4]

Figures 7.3 and 7.4 show how the cost avoidance from CNS/ATM compliance varies from these baseline values under different assumptions. Chapter Three describes the assumptions underlying each case in greater detail. Figure 7.5 presents a yearly breakdown of the cumulative cost avoidance for each modernization path.

AMP is in the early stages of implementation, with $3.55 billion in upgrade costs remaining in the program. Figure 7.3 shows the additional operating costs that would be incurred if the program were not completed. The magnitude of those penalties (beyond the $31 million nonfuel cost component due to increased flying hours) depends on the price of fuel and steady-state payload weights, but the cost of this investment will exceed the CNS/ATM cost avoidance under any assumptions.

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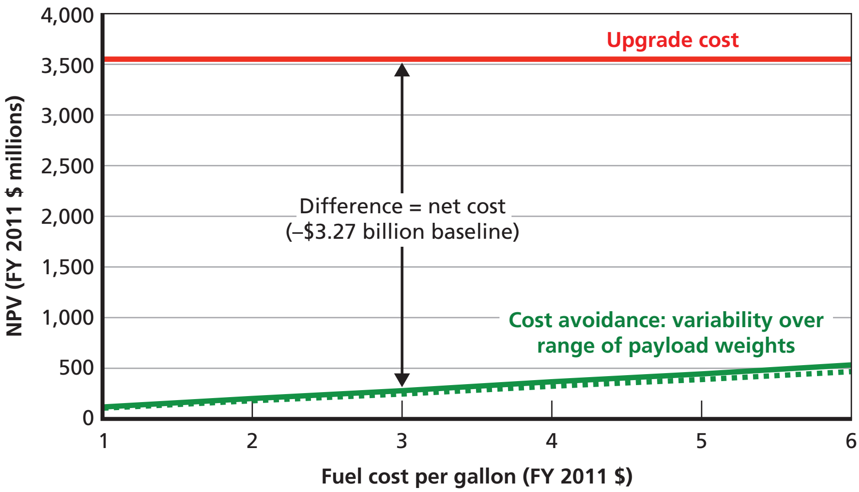
[4] This is the difference between the ADS-B Out modernization cost and the resulting cost avoidance, as shown in Table 7.2.

Figure 7.3
C-130H Cost Avoidance Through 2040 Resulting from Completing AMP as a Function of Fuel Cost and Payload Weight

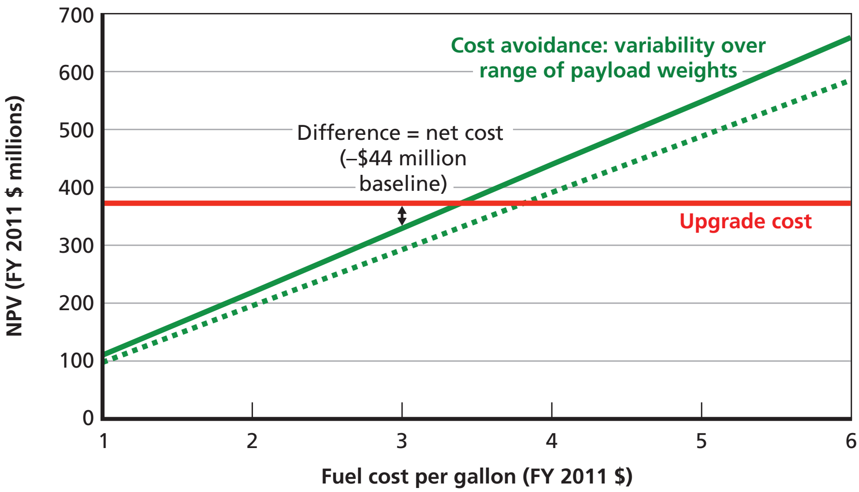


RAND *MG1194-7.3*

Current plans call for full compliance of the C-130H fleet with ADS-B Out around the time it is mandated in 2020. Figure 7.4 illustrates the implication of following through with these plans. Modernization is cost-effective only at fuel prices around $3.50 per gallon or higher, unless the upgrade program can be completed at $1.5 million or less per aircraft. There is no increase in flying hours from ADS-B Out noncompliance, since the C-130H cruises at the same true airspeed under the altitude restriction, so the nonfuel cost component is zero.

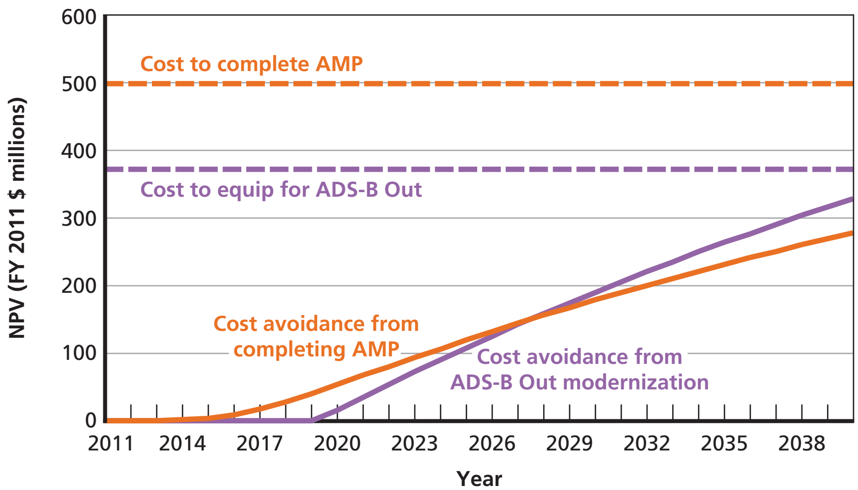
Figure 7.5 breaks down the cost avoidance associated with CNS/ATM compliance by year, showing the cumulative cost avoidance in each year from 2011 through 2040. All costs are in FY 2011 dollars and assume a constant $3 per gallon fuel price. The upgrade costs of compliance are repeated in the figure for comparison.

Figure 7.4
C-130H Cost Avoidance Through 2040 Resulting from ADS-B Out Modernization as a Function of Fuel Cost and Payload Weight



RAND *MG1194-7.4*

Figure 7.5
Yearly Cumulative Cost Avoidance Associated with C-130H CNS/ATM Compliance



RAND *MG1194-7.5*

Operational Benefits from CNS/ATM Modernization

The primary wartime mission of the C-130 is to provide intratheater airlift, moving personnel and cargo within a theater of operations. There are several reasons to discount the impact of noncompliance with CNS/ATM mandates on this mission. There is little or no civil air traffic in the theater during major combat operations. The military would control the airspace before employing intratheater airlifters, which would not be subject to civil air traffic control. Rather, an air operations center would be established for command and control, airspace deconfliction, and other functions. It is very unlikely in this scenario that the military would restrict the ability of its own aircraft to carry out the wartime mission. While there might be impacts during self-deployment to the area of responsibility, this represents a negligible portion of the overall flying that would occur over the course of the conflict.

Observations

Current and planned C-130H modernization programs are not cost-effective based solely on the cost avoidance that results from compliance with CNS/ATM mandates under the baseline assumptions used in this study; furthermore, wartime effectiveness of the fleet would not be affected if these programs were not completed. ADS-B Out modernization would be cost-effective if the upgrade costs were $1.5 million or less per aircraft. Alternatively, this program would be cost-effective at the baseline upgrade cost used in this study if fuel prices were at least $3.50 per gallon.

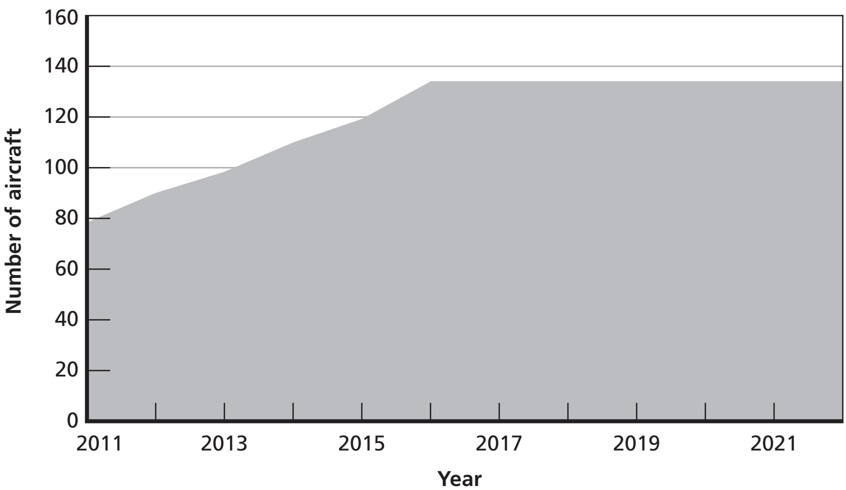
CHAPTER EIGHT

C-130J Modernization

Current Fleet Composition

There are currently 78 C-130J aircraft in the MAF fleet. This number is expected to grow at a rate of eight to 12 per year until 2016, when the fleet size should reach 134 aircraft. Figure 8.1 shows the projected fleet composition through 2022.

Figure 8.1
Projected Composition of the C-130J Fleet Through 2022



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Current and Planned Modernization Programs

There are two modernization programs planned for the C-130J fleet. The Block 7 upgrade will address navigation capability shortfalls, bringing modernized aircraft into compliance with performance-based navigation specifications down to RNAV-1 and RNP-0.3. The Block 8.1 program will equip the entire fleet with ADS-B Out within two years of the mandate, which takes effect in 2020. It will also provide FANS/CPDLC and VDL Mode 2 capabilities. Table 8.1 summarizes the C-130J's current capabilities and modernization programs. For each capability in the table, a check mark indicates compliance upon completion of the corresponding modernization program.

Currently, no aircraft have undergone either upgrade. The Block 7 program should be complete by 2016, while completion of

Table 8.1
Current C-130J Capabilities and Avionics Upgrade Programs

		Avionics Upgrade Programs	
Category	**Capability**	**Block 7**	**Block 8.1**
Communication	8.33-kHz VHF	Existing capability	
	CPDLC/FANS		√
	SATCOM data link		√
	SATCOM voice	Existing capability	
	VHF data link (VDL Mode 2)		√
Navigation	RNAV-1 (PRNAV)	√	
	RNAV-2 (U.S. RNAV)	√	
	RNP-4 (oceanic/remote)	√	
	RNP-0.3/1/2	√	
	RVSM	Existing capability	
Surveillance	ADS-B Out		√
	Mode S enhanced surveillance	Existing capability	

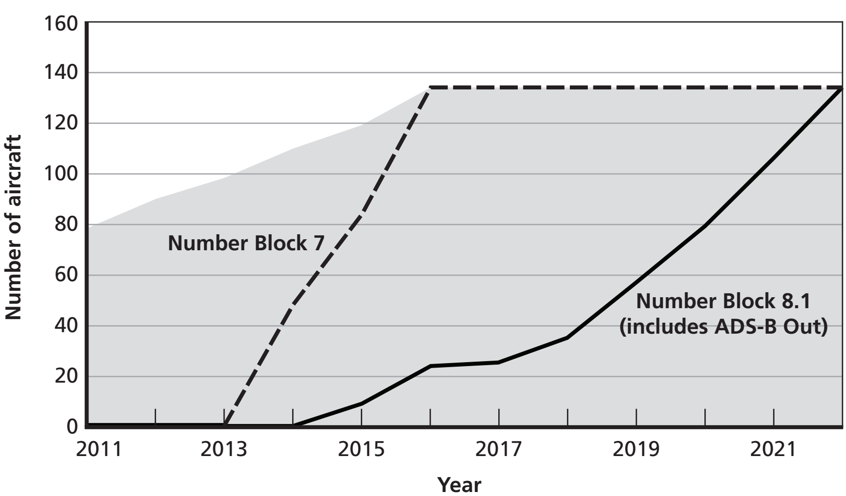
the Block 8.1 program is expected in 2022. Figure 8.2 shows the projected modernization path for the C-130J.

Operating Cost Avoidance from CNS/ATM Modernization

We used the flying pattern in the GDSS data set, supplemented by the representative training flight profile (see Appendix B), as the baseline for C-130J steady-state mobility operations through 2040. In this section, we present the results based on the analytical approach described in Chapter Three.

If the Block 7 and 8.1 programs are continued as planned, \$10 million in additional steady-state operating costs will be incurred due to noncompliance with CNS/ATM mandates, since the programs are late in meeting several mandates. Upon completion of the Block 7 program, modernized aircraft will avoid many of these operating costs. The NPV of CNS/ATM cost avoidance through 2040 resulting from completion of the Block 7 program is \$103 million. Accounting for the \$183 million in upgrade costs remaining in the program, completing

Figure 8.2
Projected Modernization Path for the C-130J Fleet Through 2022



RAND *MG1194-8.2*

it will lead to a net cost of $80 million, meaning that the remaining program is not cost-effective based on steady-state CNS/ATM cost avoidance *alone* unless fuel prices reach and remain at $5.50 per gallon. There may be additional benefits to this program that were beyond the scope of this study.

Since these aircraft tend to cruise at lower altitudes than the larger aircraft included in the study, the altitude restrictions associated with ADS-B Out noncompliance have less impact, and the cost avoidance from ADS-B Out modernization is less substantial. While equipping the entire fleet for ADS-B Out would cost approximately $221 million, the resulting cost avoidance would be only $169 million. These results are summarized in Table 8.2. For ADS-B Out modernization to be cost-effective, the upgrade cost would need to be $1.3 million or less or fuel prices would need to reach and remain at $4 per gallon.[1]

ADS-B Out compliance will be required to access Class B and C airspace, and failure to modernize would restrict access to many of the

Table 8.2
Summary of Net Present Value of C-130J Modernization Paths

	NPV (FY 2011 $ millions)			
Modernization Program	CNS/ATM Cost Avoidance	Upgrade Cost	Net Cost Avoidance	Break-Even Cost
Block 7	103	183	–80	$5.50/gal fuel
Block 8.1 (ADS-B Out)	169	221	–52	$4.00/gal fuel or $1.3 million upgrade

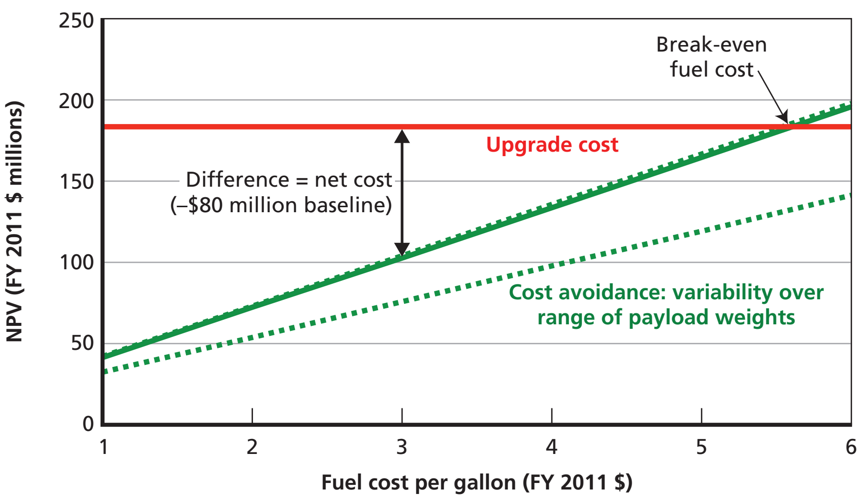
[1] The FY 2012 President's Budget shows total procurement funding of $180.7 million for the C-130 Block 7 program. This includes 117 units at an average unit procurement cost of $1.5 million (Executive Office of the President, 2011). The total procurement funding for the Block 8 program is listed as $451.6 million. This program addresses a number of capabilities unrelated to CNS/ATM, and there is not sufficient detail in the budget to estimate the cost of the ADS-B Out upgrade component. As detailed in Chapter Three, a conservative unit procurement cost estimate of $2 million was used for all aircraft included in the study. That value is used for the Block 8.1 unit cost in this chapter, rather than the higher cost that would result from the budgeted value, since ADS-B Out is the only included capability that affects steady-state operating costs related to airspace access.

busiest airports in the country. This includes several joint civil-military bases where C-130s are currently stationed. If these aircraft must be rebased due to ADS-B Out noncompliance, the case for modernization would be strengthened, since the upgrade would result in additional cost avoidance. An analysis of the effects on basing was beyond the scope of this study, but any C-130J costs resulting from ADS-B Out noncompliance and exceeding $52 million would make modernization cost-effective.[2]

Figures 8.3 and 8.4 show how the cost avoidance from CNS/ATM compliance varies from these baseline values under different assumptions. Chapter Three describes the assumptions underlying each case in greater detail. Figure 8.5 presents a yearly breakdown of the cumulative cost avoidance for each modernization path.

The Block 7 upgrade has not yet begun, but it is anticipated to cost $183 million. Figure 8.3 shows the additional operating costs that

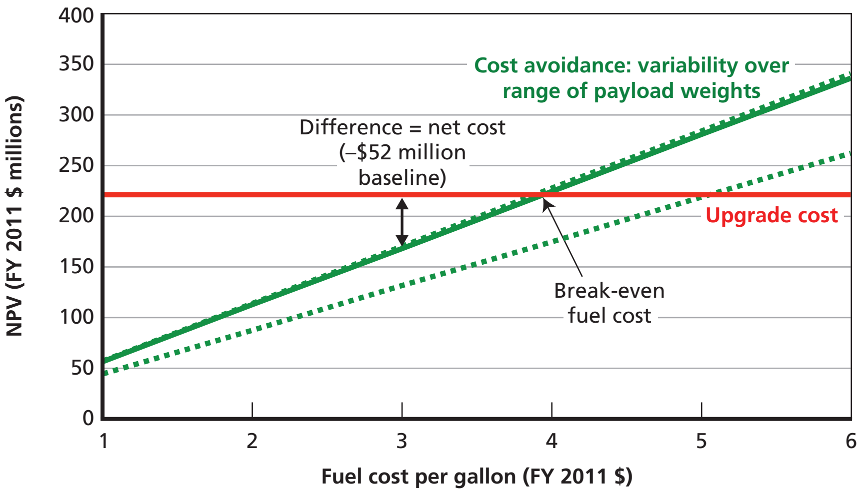
Figure 8.3
C-130J Cost Avoidance Through 2040 Resulting from Completing Block 7 Upgrade as a Function of Fuel Cost and Payload Weight



RAND *MG1194-8.3*

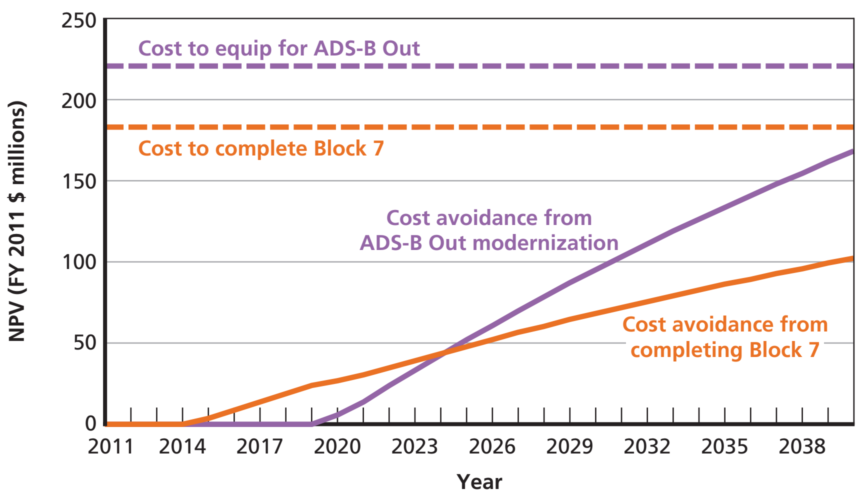
[2] This is the difference between the ADS-B Out modernization cost and the resulting cost avoidance, as shown in Table 8.2.

Figure 8.4
C-130J Cost Avoidance Through 2040 Resulting from ADS-B Out Modernization as a Function of Fuel Cost and Payload Weight



RAND *MG1194-8.4*

Figure 8.5
Yearly Cumulative Cost Avoidance Associated with C-130J CNS/ATM Compliance



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would be incurred if the program were not completed. The magnitude of those penalties (beyond the $10 million nonfuel cost component due to increased flying hours) depends on the price of fuel and steady-state payload weights, and the cost of this investment will exceed the CNS/ATM cost avoidance unless fuel costs reach and remain at $5.50 per gallon.

Current plans call for the C-130J fleet's full compliance with ADS-B Out two years after it is mandated in 2020. Figure 8.4 illustrates the implication of following through with these plans. Modernization is cost-effective only at fuel prices of $4 per gallon or higher, unless the upgrade program can be completed at a price of $1.3 million or less per aircraft.

Figure 8.5 breaks down the cost avoidance associated with CNS/ATM compliance by year, showing the cumulative cost avoidance in each year from 2011 through 2040. All costs are in FY 2011 dollars and assume a constant $3 per gallon fuel price. The upgrade costs of compliance are repeated in the figure for comparison.

Observations

Current and planned C-130J modernization programs are not cost-effective based solely on the cost avoidance that results from compliance with CNS/ATM mandates under the baseline assumptions used in this study; furthermore, the wartime effectiveness of the fleet would not be affected if these programs were not completed. Block 7 upgrades would be cost-effective if fuel prices were at least $5.50 per gallon. ADS-B Out modernization would be cost-effective if the upgrade costs were $1.3 million or less per aircraft. Alternatively, this program would be cost-effective at the baseline upgrade cost used in this study if fuel prices were at least $4 per gallon.

CHAPTER NINE

Conclusions

Ongoing and future airspace modernization programs around the world require aircraft to equip with certain CNS/ATM capabilities or face possible operating restrictions. The MAF fleet frequently operates in regions with future mandates that will not be met without modernization. Based on the cost avoidance resulting from compliance, we found that ADS-B Out upgrade programs were cost-effective for the C-5, C-17, and KC-135, avoiding more than $5.7 billion through 2040. Similar modernization for the C-130 is cost-effective only if the upgrade can be accomplished for no more than $1.5 million for the H model and $1.3 million for the J model, which are lower costs than the conservative estimate used in this study, or if fuel prices increase to $3.50 per gallon for the H model and $4.00 per gallon for the J model. If noncompliant C-130s currently operating out of joint civil-military bases must be rebased, the case for ADS-B Out modernization would be strengthened, since the upgrade would result in additional cost avoidance.

Additionally, we found that ongoing modernization programs are cost-effective for the C-5 and C-17. The C-130H AMP costs far more than the resulting CNS/ATM cost avoidance under any assumptions, although there are other benefits to the program. The C-130J block upgrades are cost-effective only if fuel prices increase and remain very high (near $5.50 per gallon or higher through 2040). Table 9.1 summarizes the cost avoidance and break-even costs for each modernization program.

The wartime deployment mission would be affected by CNS/ATM noncompliance, and we found that the C-5 and C-17 would be less effective in this role unless current modernization programs were completed and ADS-B Out modernization was completed prior to the 2020 mandate in the United States. This reinforces the results of the cost-effectiveness analysis that was based on the steady-state operating cost avoidance associated with modernization.

C-130 wartime missions would not be affected, and the fully compliant KC-135 would also maintain its current level of wartime effectiveness, so the results of the steady-state cost-effectiveness analysis are unaffected by wartime considerations for these aircraft.

Table 9.1
Net Cost Avoidance of All Modernization Programs

Modernization Program		NPV (FY 2011 $ millions)			
		CNS/ ATM Cost Avoidance	Upgrade Cost	Net Cost Avoidance	Break-Even Cost
C-5	AMP	56	46	10	NA
	ADS-B Out	1,191	136	1,055	NA
C-17	GATM/RNP-1	361	142	219	NA
	CNS/ATM Phase I (ADS-B Out)	3,666	390	3,276	NA
KC-135	ADS-B Out	1,952	504	1,448	NA
C-130H	AMP	280	3,549	–3,269	NA
	ADS-B Out	329	373	–44	$3.50/gal fuel or $1.5 million upgrade
C-130J	Block 7	103	183	–80	$5.50/gal fuel
	Block 8.1 (ADS-B Out)	169	221	–52	$4.00/gal fuel or $1.3 million upgrade

APPENDIX A

CNS/ATM Capability Descriptions

This appendix briefly describes CNS/ATM capabilities according to the categories defined in Chapter Two: communication, navigation, surveillance, and other.

Communication

Current and projected CNS/ATM communication capabilities include the following:

- *8.33-kHz radios.* 8.33-kHz radios are VHF voice radios that divide each standard 25-kHz voice channel into three separate 8.33-kHz channels, allowing a larger number of overall frequencies for controller-pilot voice communications (853d Electronic Systems Group, 2008).
- *High-frequency voice systems.* High-frequency radios for analog voice communication are capable of beyond-line-of-site communication.
- *High-frequency data-link systems.* These systems operate via high-frequency data radios to support air operations centers and, in the future, ATC applications. They have not been approved for oceanic tracks due to technical problems (853rd Electronic Systems Group, 2008).
- *Satellite communication (SATCOM) systems.* SATCOM systems provide data, voice, and fax capabilities, allowing aircraft to communicate in oceanic and remote areas where line-of-site commu-

nication systems are not available (except the north and south poles). Military command and control and civil ATC SATCOM systems are generally incompatible with each other (853rd Electronic Systems Group, 2008). SATCOM capabilities currently in use are SATCOM data-link and SATCOM voice systems.

- *Controller-pilot data-link communication (CPDLC).* CPDLC is a data communication application for text-based communication between pilots and controllers that augments voice traffic. It is available in Europe via VDL Mode 2 and the Aeronautical Telecommunications Network. FANS-1/A is an avionics package that provides CPDLC capability (plus ADS-C) in oceanic airspace using the Aircraft Communications Addressing and Reporting System.
- *VHF Data Link (VDL) Mode 2.* VDL Mode 2 is a data-link-only service designed to digitize VHF and improve the speed (data rate) of the VHF link (853rd Electronic Systems Group, 2008). It is the baseline technology for the Eurocontrol Link 2000+ program, which implements CPDLC services in European Airspace (Eurocontrol, undated[b]).
- *VDL Mode 4.* VDL Mode 4 was developed by Sweden for ADS-B. It has some level of approval in Europe but no projected future mandates (853rd Electronic Systems Group, 2008).

Navigation

Current and projected CNS/ATM navigation capabilities include the following:

- *Reduced vertical separation minimum (RVSM).* This guideline reduces the vertical separation between properly equipped aircraft to 1,000 feet in RVSM airspace, which is generally between the altitudes of 29,000 and 41,000 feet. RVSM adds new flight levels to reduce congestion in heavy-traffic areas (853rd Electronic Systems Group, 2008).

- *Frequency modulation (FM) immunity.* FM immunity ensures that navigation receivers are immune from interference from commercial FM radio broadcasts. It protects the receipt of VHF omnidirectional range and Instrument Landing System signals (853rd Electronic Systems Group, 2008).
- *Area Navigation (RNAV).* RNAV is a method of aircraft navigation along any desired flight path. The RNAV-X specification implies an accuracy requirement that the lateral navigation error remain less than x nautical miles at least 95 percent of the flight time by the population of aircraft operating in the airspace, on the route, or in accordance with a given procedure (Meyer and Bradley, 2001).
- *Required Navigation Performance (RNP).* RNP prescribes the system performance necessary for operation in a specified airspace based on a given required accuracy (RNP value). The basic accuracy requirement for RNP-X airspace is for the aircraft to remain within x nautical miles of the cleared position for 95 percent of the time in RNP airspace. There is an additional containment requirement for RNP operations. According to ICAO, any potential deviation greater than twice the RNP value must be annunciated with a probability of missed detection less than 10^{-5} (Meyer and Bradley, 2001). Larger RNP or RNAV values are not necessarily satisfied by meeting the requirements for a smaller value. For example, an aircraft meeting RNP-0.3 requirements does not automatically satisfy RNP values for all accuracies greater than 0.3.[1] Each specification may have unique requirements, depending on what phase of flight it is intended for and where it is being implemented.

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1 According to ICAO,

> [W]hen an aircraft's capability meets the requirements of a more stringent RNP airspace, based on specific infrastructure, this capability might not meet the requirements of a less stringent RNP airspace (due to the lack of supporting infrastructure appropriate to its navigation equipment fit), e.g., RNP-1 [distance measurement equipment/distance measurement equipment–only] certified aircraft [are] not capable of operation in RNP-10 (oceanic) airspace. (Meyer and Bradley, 2001, p. 3)

- *RNP-12.6.* RNP-12.6 is the navigation performance required for North Atlantic Minimum Navigation Performance Specification airspace (853rd Electronic Systems Group, 2008).
- *Basic area navigation.* Basic area navigation is a European requirement for RNAV that meets RNP-5 accuracy (853rd Electronic Systems Group, 2008).

Surveillance

Current and projected CNS/ATM surveillance capabilities include the following:

- *Mode-Select (Mode S).* The primary role of the Mode S transponder is to "selectively" respond to interrogations (as opposed to responding to all interrogations) from a sensor to provide airborne data information, including identification, equipage, and altitude. Enhanced Mode S additionally provides magnetic heading, indicated airspeed, Mach number, vertical rate, roll angle, track angle rate, true track angle, ground speed, and selected altitude (853rd Electronic Systems Group, 2008).
- *Automatic Dependent Surveillance–Broadcast (ADS-B).* The ADS-B surveillance function is based on position data computed by airborne equipment and sent to the ground system. ADS-B Out–equipped aircraft can regularly broadcast messages reporting the aircraft's position, velocity, and other information. ADS-B In–equipped aircraft have the additional capability to receive this information from other aircraft and display it in the cockpit (853rd Electronic Systems Group, 2008).
- *Traffic Alert and Collision Avoidance System.* This system comprises a family of airborne devices that function independently of the ground-based ATC system and provide collision avoidance protection (853rd Electronic Systems Group, 2008).

Other

Other capabilities that do not fall into the previously discussed categories of communication, navigation, or surveillance include the following:

Navigation Safety

- *Cockpit voice recorder.* This device records the flight crew's voices and other sounds inside the cockpit. In the event of an aircraft accident, it helps reconstruct the events leading to the accident. The device is one of the two "black boxes" often mentioned in news reports in the aftermath of aviation accidents (853rd Electronic Systems Group, 2008).
- *Emergency locator transmitter.* The emergency locator transmitter is a device contained in a crash-resistant box that emits a signal to aid in locating a downed aircraft (853rd Electronic Systems Group, 2008).
- *Terrain awareness and warning system.* These systems warn pilots of terrain proximity to prevent flight into terrain or other obstacles by comparing an aircraft's position information to a terrain database.
- *Flight data recorder.* This device records many different operating conditions, including flight time, altitude, airspeed, heading, aircraft attitude, engine parameters, control surface positions, and the status of aircraft systems. The flight data recorder is one of the two "black boxes" often mentioned in news reports of aviation accidents (853rd Electronic Systems Group, 2008).
- *Wind shear.* A reactive wind-shear system processes data from standard aircraft instruments to determine the presence of wind shear. A predictive wind-shear system uses aircraft weather radar to look forward and provide ten to 40 seconds of warning (853rd Electronic Systems Group, 2008).

Approach

- *Wide Area Augmentation System.* This FAA-developed space-based augmentation system is used to improve the accuracy, integrity, and availability of GPS (FAA, 2012).
- *Local Area Augmentation System.* This FAA-developed ground-based augmentation system provides differential corrections to the GPS signal to enable precision-landing operations. It provides greater accuracy than the Wide Area Augmentation System.
- *Microwave landing system.* This ground-based landing system was designed to replace the Instrument Landing System. It has largely fallen out of favor with the advent of RNP-based landing procedures and equipment.
- *Localizer performance with vertical guidance.* These procedures identify Wide Area Augmentation System vertical guidance approach minimums with electronic lateral and vertical guidance. The obstacle clearance area is considerably smaller than the lateral and vertical navigation protection, allowing lower minima in many cases (FAA, 2012).
- *Lateral and vertical navigation.* Guidance-approach minimums for lateral and vertical navigation have been developed to accommodate an RNAV instrument approach with vertical guidance, but the lateral and vertical integrity limits are larger than with a precision approach or localizer performance with vertical guidance (FAA, 2012).

Military

- *M-code.* M-code is a military signal designed to further improve the antijamming and secure access of military GPS signals.
- *Mode 5.* Mode 5 is a transponder mode mandated by the office of the Secretary of Defense to replace Mode 4. Mode 5 incorporates advanced encryption and additional functionality similar to ADS-B, including position and identification information.

- *Selective Availability/Anti-Spoofing Module (SAASM).* This module allows the decryption of precise GPS signals and is the newest generation of security architecture for military GPS users.

APPENDIX B

GDSS Steady-State Operations Patterns

This appendix describes the steady-state operations patterns for the mobility fleets included in this study based on GDSS data from 2000 to 2010. As indicated by the legends, the orange and red lines represent the most commonly flown routes. Some of them represent training missions in which aircraft depart from and arrive at the same base; GDSS does not include sufficient detail to reconstruct these missions without additional data. We consulted operational units to create representative flight profiles for this subset of missions. These profiles are included in this appendix for each aircraft except the C-130, which flies nearly all training missions at low altitude, where they would not be affected by CNS/ATM mandates.

C-5 Operations Pattern

Figure B.1 shows the great circle routes connecting base pairs listed in the GDSS database for the C-5 during the period from 2000 to 2010.

Approximately 11 percent of the C-5 training sorties depart from and arrive at the same base, with around one-quarter flown at low altitude where they would not be affected by CNS/ATM mandates. The remaining missions typically include high-altitude segments that would be affected by mandates. Figure B.2 shows the flight profile used to represent this subset of missions.

Figure B.1
C-5 Steady-State Operations Pattern, 2000–2010

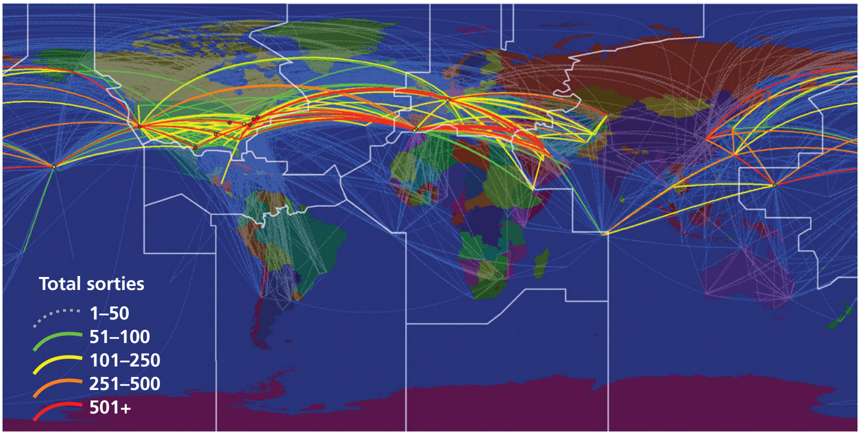

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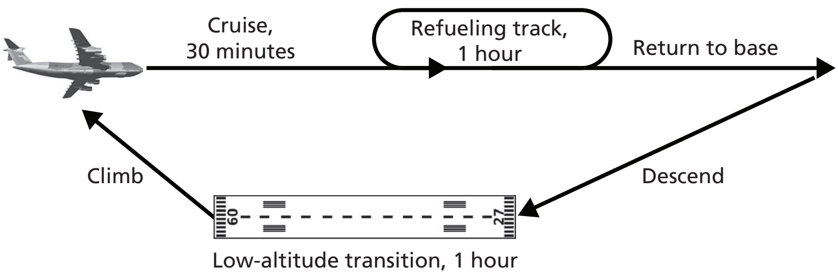
Figure B.2
Representative Flight Profile for C-5 High-Altitude Training Missions That Would Be Affected by CNS/ATM Mandates



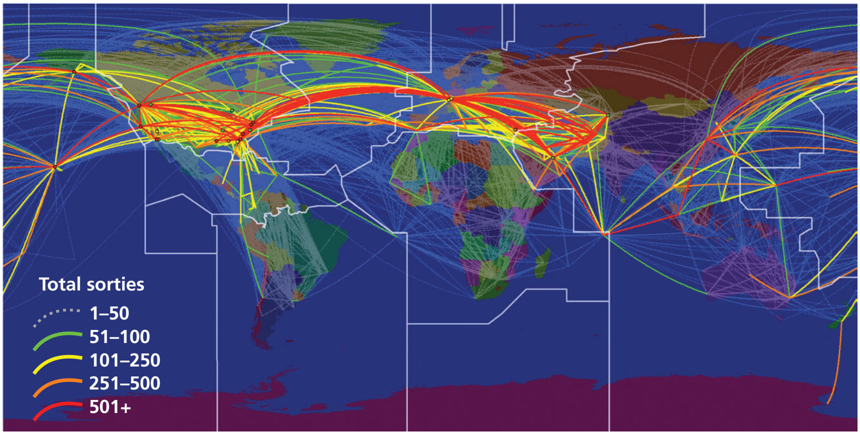
RAND *MG1194-B.2*

C-17 Operations Pattern

Figure B.3 shows the great circle routes connecting base pairs listed in the GDSS database for the C-17 during the period from 2000 to 2010.

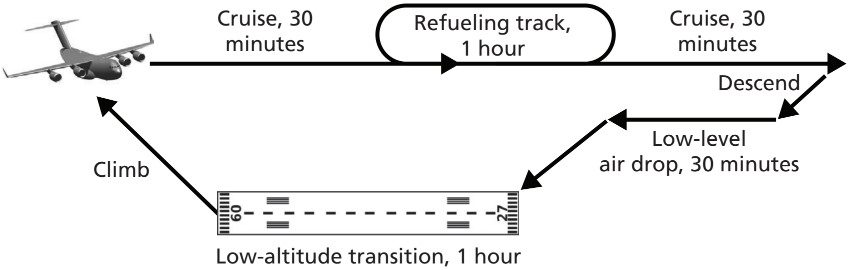
Approximately 12 percent of the C-17 training sorties depart from and arrive at the same base, with around 40 percent flown at low altitude where they would not be affected by CNS/ATM mandates. The remaining missions typically include high-altitude segments that would be affected by mandates. Figure B.4 shows the flight profile used to represent this subset of missions.

Figure B.3
C-17 Steady-State Operations Pattern, 2000–2010



RAND *MG1194-B.3*

Figure B.4
Representative Flight Profile for C-17 High-Altitude Training Missions That Would Be Affected by CNS/ATM Mandates



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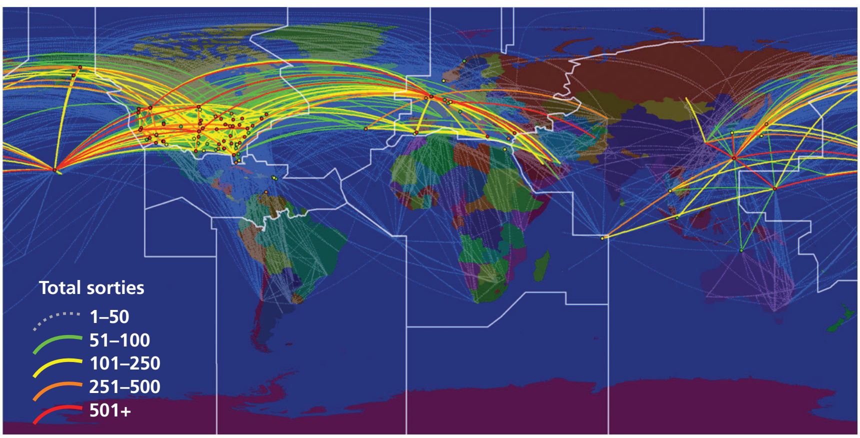
KC-135 Operations Pattern

Figure B.5 shows the great circle routes connecting base pairs listed in the GDSS database for the KC-135 during the period from 2000 to 2010.

Unlike the strategic airlifters, sorties that return to the same base from which the aircraft departed account for a significant fraction of KC-135 flying time—approximately 65 percent of sorties. These include both operational and training missions. Approximately 10 percent of these missions are flown at low altitude where they would not be affected by CNS/ATM mandates. The remaining missions typically include high-altitude segments that would be affected by mandates. Figure B.6 shows the flight profile used to represent this subset of missions.

Figure B.5
KC-135 Steady-State Operations Pattern, 2000–2010



RAND *MG1194-B.5*

C-130 Operations Pattern

Figure B.7 shows the great circle routes connecting base pairs listed in the GDSS database for the C-130 during the period from 2000 to 2010. Approximately 40 percent of C-130 sorties depart from and

Figure B.6
Representative Flight Profile for KC-135 High-Altitude Same-Base Missions That Would Be Affected by CNS/ATM Mandates

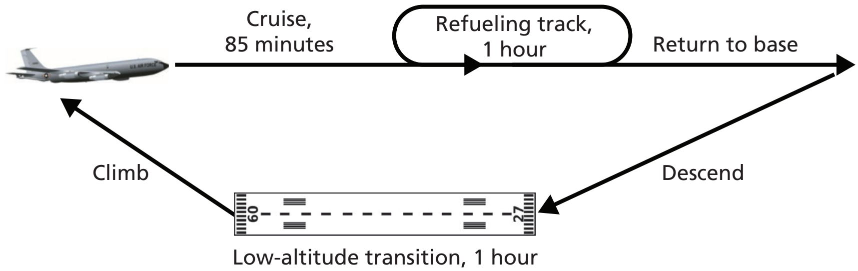


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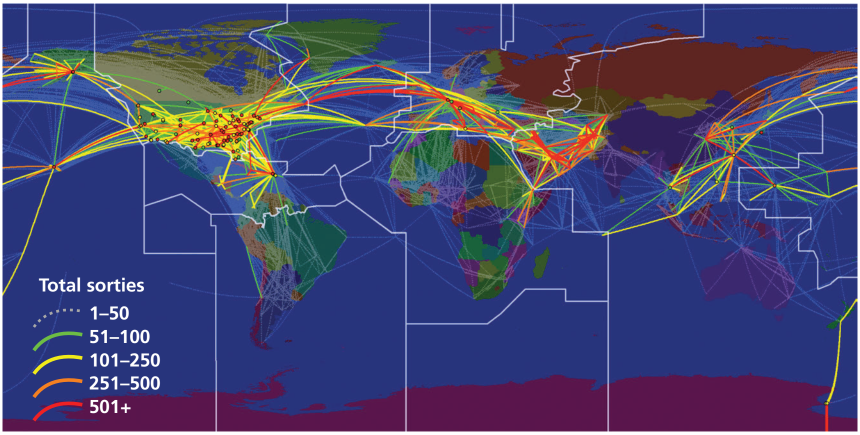
Figure B.7
C-130 Steady-State Operations Pattern, 2000–2010



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arrive at the same base. Unlike the larger aircraft included in this study, nearly all of these missions are flown at low altitude and would not be affected by CNS/ATM mandates.

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